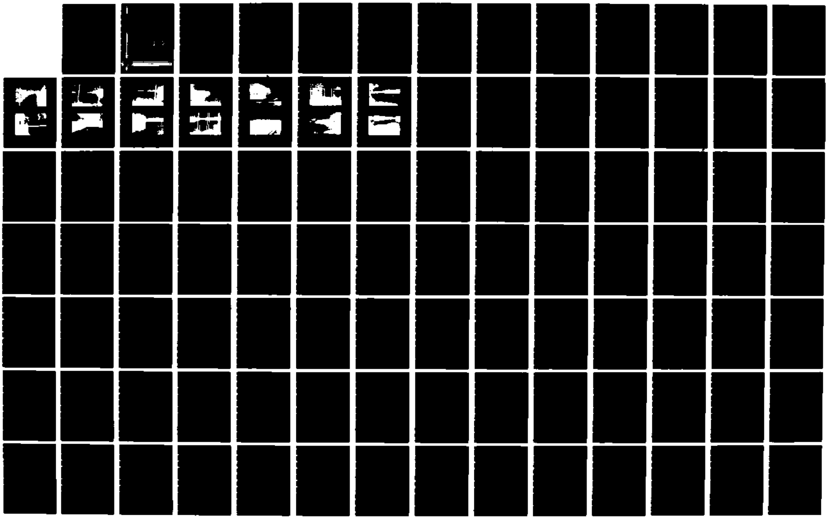
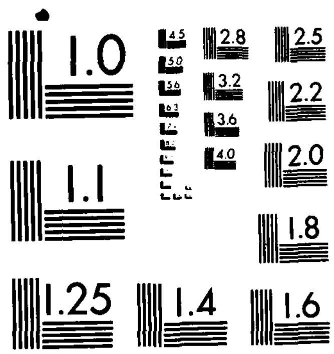
AD-A161 970 CLARKS HILL LAKE WATER QUALITY STUDY(U) APPLIED BIOLOGY 1/2
INC DECATUR GA JUN 82 DACW21-81-C-0011

UNCLASSIFIED F/G 8/8 NL




1.0
4.5
5.0
5.6
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

AD-A161 970

(12)

CLARKS HILL LAKE WATER QUALITY STUDY

JUNE 1982

APPLIED BIOLOGY, INC.

641 DeKalb Industrial Way • Decatur, Georgia 30033 • (404) 296-3900

85 12 ... 024

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AI61970	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Clarks Hill Lake Water Quality Study		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) --------		8. CONTRACT OR GRANT NUMBER(s) DACW21-81-C-0011
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Biology, Inc. 641 DeKalb Industrial Way Decatur, GA 30033		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Engineer District, Savannah P. O. Box 889 Savannah, GA 31402-0889		12. REPORT DATE June 1982
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Clarks Hill Lake
Georgia
South Carolina
Savannah River
Water quality
Sediments
Chemical contamination

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study of selected chemical, physical and biological parameters from Clarks Hill Lake, Georgia and South Carolina, was conducted by Applied Biology, Inc., for the Department of the Army, Savannah District Corps of Engineers from February to October 1981. Data are presented for 20 sampling sites located in Clarks Hill Lake, its tributaries and portions of the Savannah River downstream from the dam. Water and sediment chemical and physical parameters; macroinvertebrate, phytoplankton, zooplankton and periphyton community composition and density; bacteriological parameters; and pesticide and

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) heavy metal concentrationa from tissues of mollusc (Corbicula), white catfish and largemouth bass were analyzed.

Clarks Hill Lake is characterized by large annual temperature variationa and development of strong thermal gradients during summer stratification. Deep hypolimnion waters gradually become depleted of dissolved oxygen by late summer. Clarks Hill Lake waters are soft and have a low carbonate-bicarbonate buffering capacity, resulting in fluctuations in pH, conductivity and various other physicochemical parameters between the epilimnion and hypolimnion during summer stratification.

Total phosphate concentrations in Clarks Hill Lake are high. The Savannah and Broad Rivers and the Georgia and South Carolina Little Rivers are major sources of phosphate input into the lake. Total phosphate levels have increased at lake and tributary stations since a 1973 study at Clarks Hill Lake. Although total phosphate levels are high, they are within the range of those observed in other southeastern lakes and reservoirs.

Determination of various pesticide concentrations in sediments and in tissue samples from Corbicula, white catfish and largemouth bass showed no apparent contamination or biomagnification of these parameters within Clarks Hill Lake. Heavy metal concentrations in sediments, tissues and wholewater samples were generally higher at tributary stations than at lake stations.

Primary productivity in Clarks Hill Lake is generally limited by low orthophosphate and nitrate-nitrite concentrations. Present nutrient concontrations are below critical values at which algal blooms commonly occur. Phytoplankton densities and chlorophyll-a measurements showed a seasonal pattern of increasing productivity from early spring through the fall. Standing crops were high at tributary stations and lowest near the dam. A similar pattern of density distribution was also noted for the zooplankton community of Clarks Hill Lake.

The benthic and drift macroinvertebrate communities of the lake were low in density and diversity as compared to other southeastern lakes and reservoirs. The benthos was predominated by the Asiatic clam, Corbicula fluminea, and the drift community was predominated by chironomid insects.

The overall trophic condition of Clarks Hill Lake can be considered Mesotrophic, characteristic of waters with moderate nutrient concentrations. Data from the major tributaries entering the lake suggest that the Georgia and South Carolina Little Rivers, the Broad and upper Savannah Rivers are eutrophic.

CLARKS HILL LAKE

WATER QUALITY STUDY

JUNE 1982

Prepared for

U.S. ARMY CORPS OF ENGINEERS

SAVANNAH DISTRICT

CONTRACT NO. DACW 21-81-C-0011

Prepared by

APPLIED BIOLOGY, INC.
641 DeKalb Industrial Way
Decatur, Georgia 30033

CONTENTS

CONTENTS
(continued)

ABSTRACT

A study of selected chemical, physical and biological parameters from Clarks Hill Lake, Georgia and South Carolina, was conducted by Applied Biology, Inc., for the Department of the Army, Savannah District Corps of Engineers from February to October 1981. Data are presented for 20 sampling sites located in Clarks Hill Lake, its tributaries and portions of the Savannah River downstream from the dam. Water and sediment chemical and physical parameters; macroinvertebrate, phytoplankton, zooplankton and periphyton community composition and density; bacteriological parameters; and pesticide and heavy metal concentrations from tissues of mollusc (Corbicula), white catfish and largemouth bass were analyzed.

Clarks Hill Lake is characterized by large annual temperature variations and development of strong thermal gradients during summer stratification. Deep hypolimnion waters gradually become depleted of dissolved oxygen by late summer. Clarks Hill Lake waters are soft and have a low carbonate-bicarbonate buffering capacity, resulting in fluctuations in pH, conductivity and various other physicochemical parameters between the epilimnion and hypolimnion during summer stratification.

Total phosphate concentrations in Clarks Hill Lake are high. The Savannah and Broad Rivers and the Georgia and South Carolina Little Rivers are major sources of phosphate input into the lake. Total phosphate levels have increased at lake and tributary stations since a 1973 study at Clarks Hill Lake. Although total phosphate levels are high, they are within the range of those observed in other southeastern lakes and reservoirs.

Determination of various pesticide concentrations in sediments and in tissue samples from Corbicula, white catfish and largemouth bass showed no apparent contamination or biomagnification of these parameters within Clarks Hill Lake. Heavy metal concentrations in sediments, tissues and wholewater samples were generally higher at tributary stations than at lake stations.

Primary productivity in Clarks Hill Lake is generally limited by low orthophosphate and nitrate-nitrite concentrations. Present nutrient concentrations are below critical values at which algal blooms commonly occur. Phytoplankton densities and chlorophyll-*a* measurements showed a seasonal pattern of increasing productivity from early spring through the fall. Standing crops were high at tributary stations and lowest near the dam. A similar pattern of density distribution was also noted for the zooplankton community of Clarks Hill Lake.

The benthic and drift macroinvertebrate communities of the lake were low in density and diversity as compared to other southeastern lakes and reservoirs. The benthos was predominated by the Asiatic clam, Corbicula fluminea, and the drift community was predominated by chironomid insects.

The overall trophic condition of Clarks Hill Lake can be considered mesotrophic, characteristic of waters with moderate nutrient concentrations. Data from the major tributaries entering the lake suggest that the Georgia and South Carolina Little Rivers, the Broad and upper Savannah Rivers are eutrophic.

A. INTRODUCTION

Clarks Hill Dam and Lake (Figure A-1) is a multipurpose project designed to reduce flooding on the Savannah River, generate electric power and increase the depth of the Savannah River for navigation downstream from Augusta, Georgia. Clarks Hill Dam is located 386.2 kilometers above the mouth of the Savannah River, between Georgia and South Carolina, approximately 35 kilometers above Augusta, Georgia. The Savannah District U.S. Army Corps of Engineers began construction of the dam in August 1946 and completed the lake in July 1954. Clarks Hill Dam was the first hydroelectric facility built on the Savannah River. The hydroelectric power plant at the dam has seven generators, each with a capacity of 40,000 kilowatts. The average annual energy output of Clarks Hill Power Plant is 700 million kilowatt hours. The dam maintains a minimum release flow of 5800 cubic feet per second (cfs) for navigational purposes below Augusta. A typical flow of 6300 cfs is provided 80 percent of the year under normal operating conditions. The lake is designed for a maximum drawdown of 5.5 meters (18 feet) from the top of power pool elevation of 100.6 meters (330 feet msl) to a minimum pool elevation of 95.1 meters (312 feet msl).

Because of below average rainfall in Georgia and surrounding states during 1981, the pool elevation at Clarks Hill Lake receded to a near record level of 96.8 meters (317.6 feet msl) by late November (Figure A-2). Average monthly releases from Clarks Hill Dam for 1981 were below 5800 cfs for every month but January and March (Table A-1).

Clarks Hill Lake is one of the largest inland bodies of water in the southeast, providing fishing, boating, camping, hunting, picnicking and other forms of recreation to the public. The lake impounds approximately 64 kilometers of the Savannah River and portions of the Broad River and Georgia and South Carolina Little Rivers. The lake has 1930 kilometers of shoreline and provides a total flood control storage of 390,000 acre-feet of water. The mean depth of the lake is 11 meters, with a maximum depth of approximately 45 meters at the face of the dam. Clarks Hill Lake has over 15 tributaries with a combined drainage area of 15,609 square kilometers. The lake has a mean hydraulic retention time of approximately 136 days (EPA, 1976).

Applied Biology, Inc., was contracted by the Army Corps of Engineers, Savannah District, to conduct a biological and water quality investigation of Clarks Hill Lake from February through October 1981. The objectives of this study were to 1) characterize any environmental or water quality problems in the lake 2) obtain data to develop guidance for lake control/discharge water quality relationships and 3) establish baseline conditions for future comparisons and to facilitate coordination of state agencies in implementing watershed pollution control measures. Biological and water quality sampling stations were located in Clarks

Hill lake and surrounding waters (Figure A-1, Table A-2, Plates 1-14). The sampling schedule and list of measured parameters is presented in Table A-3. Climatological data is presented in Table A-4. Participating staff and their expertise are listed in Table A-5.

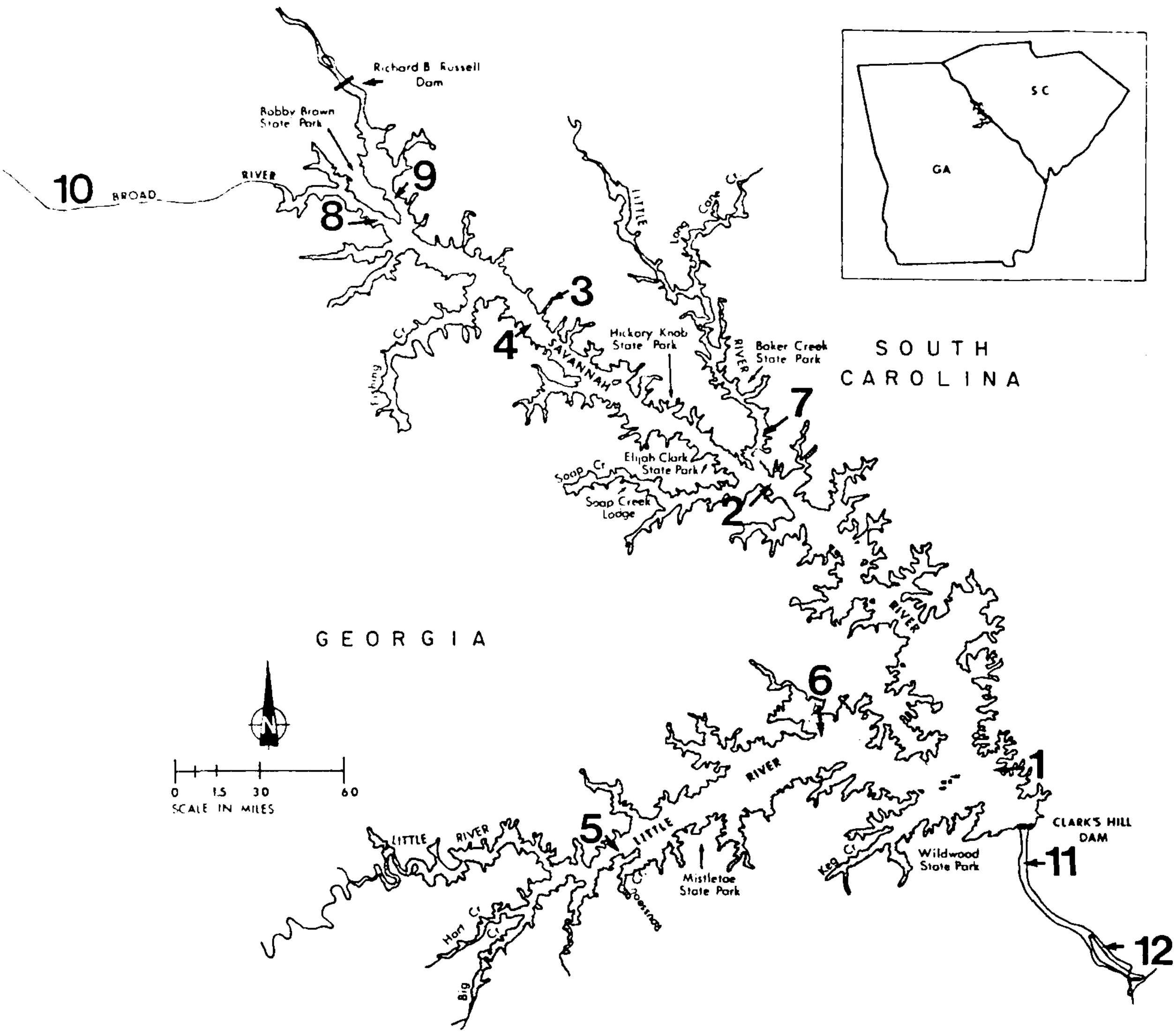


Figure A-1. Location of biological and chemical sampling stations, Clarks Hill Lake, 1981.

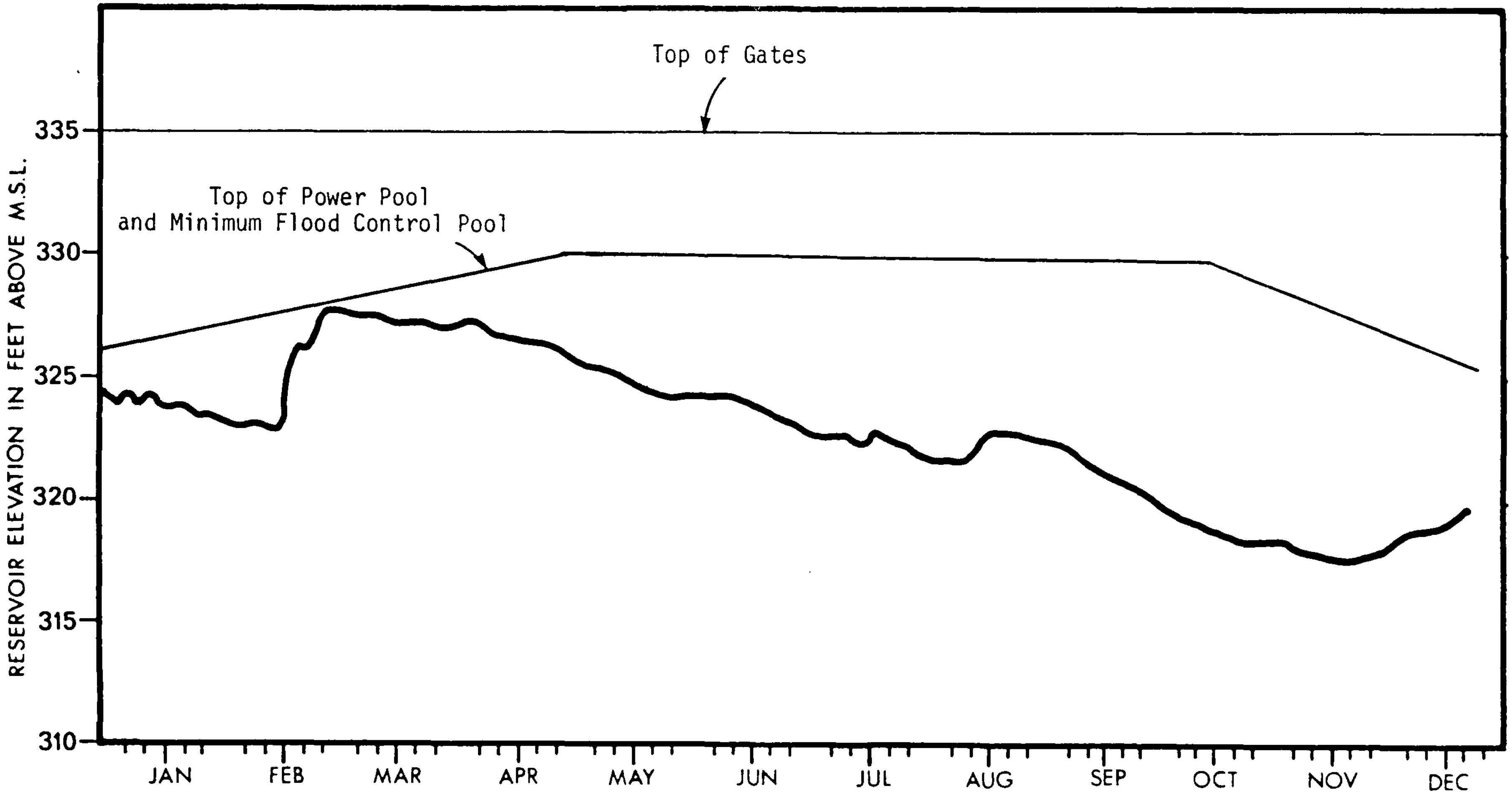


Figure A-2. Pool elevation of Clarks Hill Lake, January through December 1981.

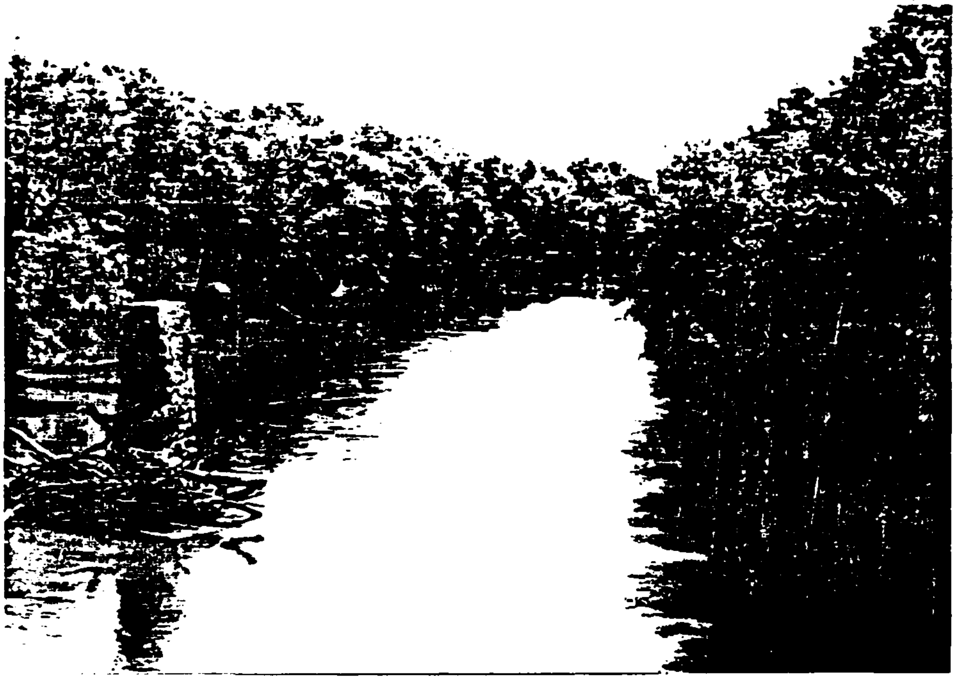


Plate 1. Station 10 on the Broad River looking downstream from Georgia Highway 17. Typical vegetation consists of sweetgum, tulip popular, white oak, water oak and other hardwoods.

Plate 2. The Broad River looking southwest from Bobby Brown State Park. Station 8 is near the opposite shore. The gradually sloping shoreline, which typifies most of Clarks Hill Lake, is evident in this photograph, as are pines, the predominant vegetation around the lake.

Plate 3. The Savannah River downstream of the Richard B. Russell Dam. Station 9 is near the right (west) shore in this view. Photographs were taken in May 1982 and lake water level is considerably higher than during the sampling period.

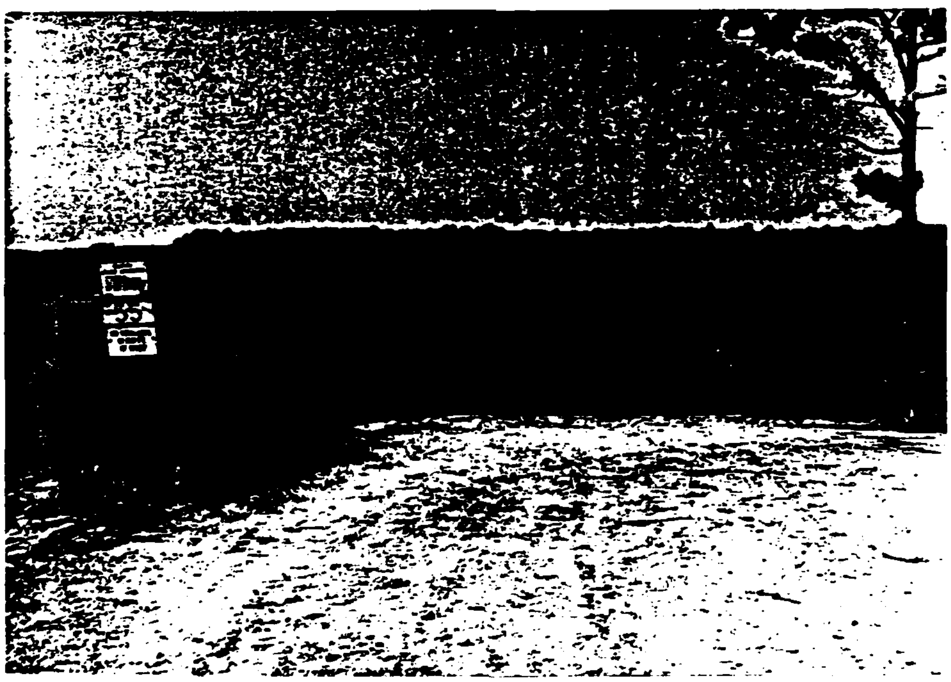


Plate 4. One of the many boat ramps around Clarks Hill Lake, this one is located at Murray Creek State Park just downstream of Station 4.

Plate 5. Clarks Hill Lake from Murray Creek State Park looking southeast toward Hickory Knob State Park.

Plate 6. Station 3, one of the many coves typical of the Clarks Hill Lake shoreline. Loblolly is the predominate pine around the lake, with lesser amounts of short leaf pine.

Plate 7. A cove near the mouth of the South Carolina Little River looking downstream toward Station 2.

Plate 8. The South Carolina Little River at Station 7.

Plate 9. Station 1 on the eastern side of Clarks Hill Lake just above the dam. There are more areas of both open beach and high relief along the shoreline just above the dam than at most other locations around the lake.

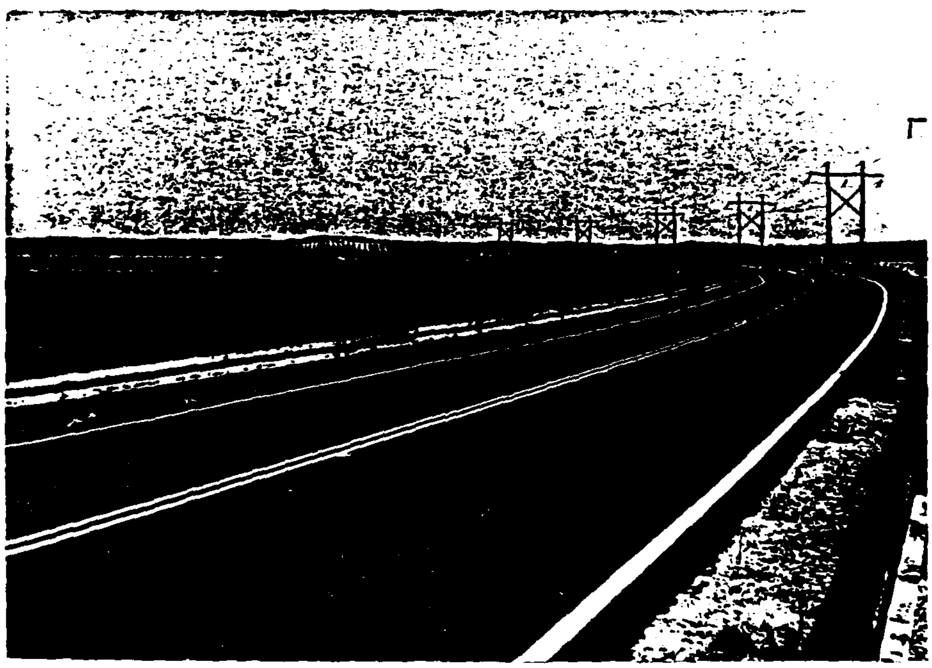


Plate 10. Georgia Highway 47 crossing the Georgia Little River about 6 km above Station 6.

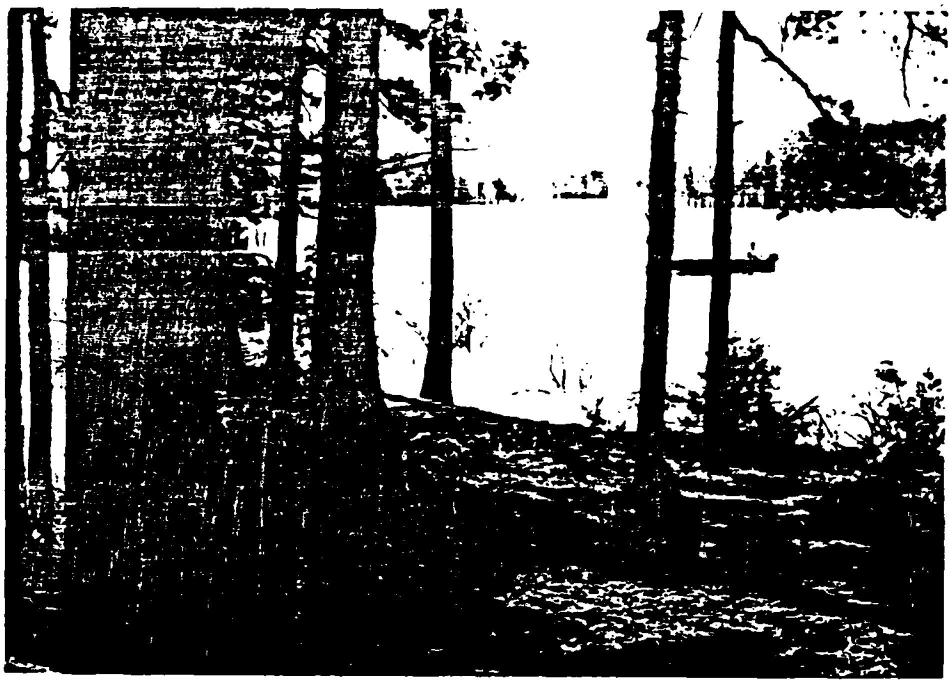


Plate 11. The Georgia Little River at a boat ramp near Station 5. Many small islands characterize this location.

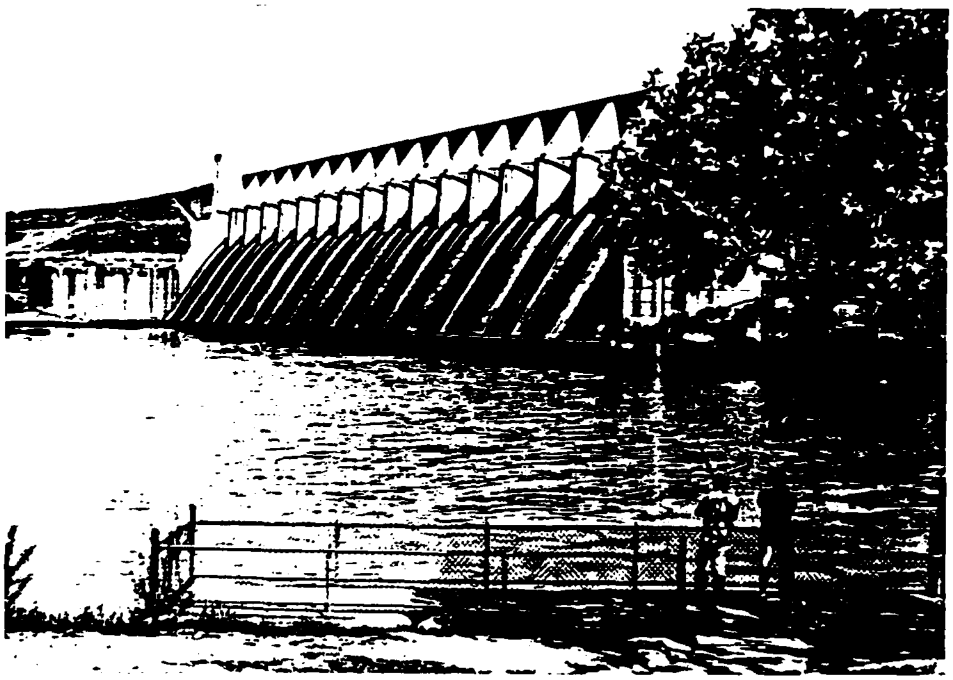


Plate 12. Fishing in the Savannah River below Clarks Hill Dam.

Plate 13. Station 11 on the Savannah River looking southwest from the boat ramp below the dam.

Plate 14. The Savannah River at Georgia Highway 28 looking upriver toward Station 12. Sycamore is one of the predominant hardwoods at this location.

TABLE A-1

AVERAGE MONTHLY RELEASES FROM CLARKS HILL DAM
CLARKS HILL LAKE
1981

Month	Releases (cfs)
January	5800
February	4800
March	6200
April	5100
May	5000
June	4800
July	4800
August	4600
September	5200
October	4600
November	3900
December	3600 (through 22 Dec)

CH8
TABLEA-1

TABLE A-2

STATION LOCATIONS
CLARKS HILL LAKE
1981

Station number	Station location
1	Located 0.8 kilometer north of Clark's Hill Dam
2	Located 24 kilometers upstream of dam at buoy marker No. 73.
3	Located in a cove on the north shore approximately 38.6 kilometers upstream of dam, adjacent buoy marker No. 118.
4	Located 41 kilometers upstream of dam at buoy marker No. 123.
5	Located in the Georgia Little River 2.4 kilometers east of Raysville Bridge (GA State Route 43) at buoy marker No. 66.
6	Located in the Georgia Little River 5.6 kilometers east of Kegg Bridge (GA State Route 47) at buoy No. 13.
7	Located in the South Carolina Little River 0.8 kilometers below pumping station at shoreline mile marker 890.
8	Located in the Broad River 4 kilometers west, northwest of buoy marker No. 135, 0.8 kilometer above shoreline mile marker 669.
9	Located at the northern end of the reservoir at buoy marker No. 138, approximately 46.6 kilometers upstream of the dam.
10	Located on the Broad River at GA State Route 17 bridge, 19.3 kilometers south of Elberton, GA

TABLE A-2
(continued)
STATION LOCATIONS
CLARK'S HILL RESERVOIR
1981

Station number	Station location
11	Located on the Savannah River 2.4 kilometers below the dam.
12	Located on the Savannah River 4.8 kilometers below the dam.
CLARK HILL MARINA	Located off highway 221, 6.4 kilometers east of Plum Branch, South Carolina
BAKER CREEK STATE PARK	Located off highway 378, 4.8 kilometers east of McCormick, South Carolina
BOBBY BROWN STATE PARK	Located on the peninsula between the confluence of the Savannah and Broad Rivers at the northern end of Clarks Hill Lake.
SOAP CREEK LODGE	Located off highway 378, 4 kilometers northeast of Lincolnton, Georgia.
MISTLETOE STATE PARK	Located off Georgia highway 150, 5 kilometers northeast of Winfield, Georgia.
HICKORY KNOB STATE PARK	Located off South Caorlina highway 7, 3.2 kilometers south of Bordeaux, South Carolina.
ELIJAH CLARK STATE PARK	Located off highway 378 where it crosses Clarks Hill Lake on the Georgia side.
WILDWOOD PARK	Located off Georgia highway 104, 3.2 kilometers northeast of Pollards, Georgia.

CHVI
TABLEA-2A

TABLE A-3

SAMPLING SCHEDULE BY PARAMETER
CLARKS HILL LAKE
1981

Parameters	Feb 22-27	Mar 16-21	Apr 27-30	Jun 22-26	Jul 20-21	Aug 24-29	Sep 21-24	Oct 26-30
<u>Water sampling</u>								
Temperature[a,b]	X			X		X		X
Dissolved oxygen[a,b]	X			X		X		X
pH[a,b]	X			X		X		X
Conductivity[a,b]	X			X		X		X
Oxidation reduction potential[a,b]	X			X		X		X
Percent light transmission[a]	X		X	X		X		X
Residue, total non-filterable[a]	X			X		X		X
Residue, total filterable	X			X		X		X
Turbidity	X			X				X
Nitrate nitrogen[a]								
Nitrite nitrogen	X			X		X		X
Ammonia[a]	X			X		X		X
TKN[a]	X			X		X		X
Phosphate, total[a]	X			X		X		X
Orthophosphate	X			X				X
Alkalinity (ph 4.5)	X			X		X		X
Free carbon dioxide[a]	X			X		X		X
Color	X			X				X
Total organic carbon[a]	X			X		X		X
Iron, total	X			X				X
Iron II	X			X				X
Manganese, total	X			X				X
Manganese, disssolved	X			X				X
Sulfide, dissolved	X							X
Unionized hydrogen sulfide (calc.)	X							X

TABLE A-3
(continued)
SAMPLING SCHEDULE BY PARAMETER
CLARKS HILL LAKE
1981

Parameters	Feb 22-27	Mar 16-21	Apr 27-30	Jun 22-26	Jul 20-21	Aug 24-29	Sep 21-24	Oct 26-30
Sulfate, total	X							X
Calcium, total	X							X
Magnesium, total	X							X
Hardness (calc.)	X							X
Sodium, total	X							X
Potassium, total	X							X
Chloride	X							X
Biochemical oxgyen demand	X			X		X		X
Chemical oxygen demand	X			X		X		X
<u>Biological sampling</u>								
Phytoplankton	X		X	X		X		X
Chlorophyll-<u>a</u>	X		X	X		X		X
Zooplankton	X		X	X		X		X
Periphyton	X		X	X		X		X
Macroinvertebrate		X			X			X
Invertebrate drift		X			X			X
Tissue analysis			X				X	
Sediment analysis			X				X	

[a]Diel parameter sampled at 3-hour intervals in August.

[b]Vertical profiles run for the eight lake stations.

CH8

TABLEA-3

TABLE A-4

WATER QUALITY STUDY
CLIMATOLOGICAL DATA[a]
CLARKS HILL LAKE

Date	Temperature F° Max	Min	Avg	Precipitation water equivalent (inches)	Sky cover tenths sunrise to sunset	midnight to midnight
21 Feb	75	37	56	0	2	1
22	72	35	54	trace amount	8	6
23	63	46	55	0.08	4	5
24	65	40	53	0	0	0
25	75	30	53	0	4	3
26	78[b]	36	57	0	0	0
27	71	38	55	0	3	2
28	77	34	56	0	9	6
16 Mar	64	39	52	0.02	2	3
17	68	28	48	0	1	1
18	68	47	58	0.75	9	7
19	53	37	45	0	6	5
20	57	32	45	0	1	1
21	65	28	47	0	9	7
22	52	41	47	0.51	10	10
23	47	39	43[b]	trace amount	10	9
27 Apr	89[b]	49	69	0	0	0
28	88	52	70	0	0	0
29	85	54	70	0	7	4
30	86	56	71	0	7	4
01 May	79	56	68	trace amount	7	5
02	76	45	61	0	0	0
03	77	41[b]	59	0	2	2
04	84	43	64	0	4	4
22 Jun	100[b]	75	88[b]	0	5	4
23	99	70	85	0	3	2
24	96	70	83	0.86	8	7
25	95	68	82	0	2	3
26	91	70	81	1.15	7	7
27	87	69	73	0	3	4
28	85	64	75	0	2	1
29	86	57[b]	72[b]	0	2	1
16 Jul	99	76	88[b]	trace amount	4	6
17	97	74	86	trace amount	4	6
18	93	72	83	trace amount	7	7
19	93	71	82	0.06	6	5
20	97	72	85	0	3	4
21	101[b]	71	86	0	2	3

TABLE A-4
(continued)
WATER QUALITY STUDY
CLIMATOLOGICAL DATA[a]
CLARKS HILL LAKE

Date	Temperature F° Max	Min	Avg	Precipitation water equivalent (inches)	Sky cover tenths sunrise to sunset	midnight to midnight
22 Jul	97	64[b]	81	0	4	2
23	98	68	83	trace amount	3	3
24 Aug	86	62	74	trace amount	2	3
25	90	63	77	0	5	3
26	85	62	74	0	6	3
27	86	59[b]	73	0	7	6
28	88	63	76	0	9	9
29	85	71	78	0	10	9
30	88	68	78	1.53	9	8
31	87	66	77	0	2	2
23 Sep	82	52	67	0	1	0
24	79	45	62	0	1	1
25	82	46	64	0	0	0
26	82	44[b]	63	0	2	1
27	84	49	67	0	3	2
28	89	54	72	0	0	0
29	84	57	71	0	0	1
30	88	58	73	0	2	2
25 Oct	48	43	46[b]	0.70	10	10
26	70	48	59	0.74	10	10
27	72	50	61	0.02	4	4
28	75	42	59	0	0	1
29	74	45	60	0	7	4
30	62	51	57	0	10	9
31	67	47	57	0	5	6
01 Nov	68	46	57	0	10	7

[a]Local climatological data obtained from the National Weather Service Office of NOAA, Augusta, Georgia.

[b]Extreme for the month.

CHVI
TABLEA-4

TABLE A-5

PARTICIPATING STAFF
CLARKS HILL LAKE WATER QUALITY STUDY
1981

David J. Herrema, M.S.	Division Director, Aquatic Sciences
William C. Howard, M.S.	Project Manager Zooplankton Taxonomy
William B. Rhodes III, M.S.	Department Head, Benthos
Douglas G. Strom, B.S.	Macroinvertebrate Taxonomy
Steve P. Dupont, M.S.	Department Head, Fish
Larry W. Neal, M.S.	Department Head Plankton-Phytoplankton Taxonomy
Robert R. Comegys, M.S.	Quality Control Manager Periphyton Taxonomy
Teresa Ratajczak	Bacteriology
Stevos N. Tsoukalas, Ph.D.	Division Director, Chemistry
Hugh M. Anderson, B.S.	Organic Chemistry
Pamela R. Gentry, B.S.	Organic Chemistry
Diana Trenova, B.S.	Heavy Metals
Rita Khurana, B.S.	Wet Chemistry
Rachel B. Fried, B.S.	Wet Chemistry
Christopher C. Ellis, B.S.	Computer Programming
Rebecca R. Martin, B.S.	Document Production

CHVI
TABLEA-5

B. CHEMISTRY

INTRODUCTION

This study was designed to monitor the chemical and physical parameters of Clarks Hill Lake and its tributaries. Monitoring of these parameters is important to the biological communities in aquatic environments because of the synergistic effects that the physical and chemical parameters have on the aquatic food chain. The purpose of this monitoring program was to 1) establish baseline conditions for future comparisons, 2) identify any existing water quality/environmental problems, and 3) establish a data base for resource managers to evaluate and utilize in the development of watershed pollution control and water-use programs.

MATERIALS AND METHODS

Physicochemical Sampling

Duplicate whole-water samples were collected at eight lake and four river stations during February, June, August and October 1981. A composite of 10 samples representing the water column was collected at the surface, at 2-m intervals down to 10 m, and then at four equally spaced depths to the bottom at lake Stations 1 through 8 (Figure A-1). Water samples from river Stations 9 through 12 were taken at mid-depth in the middle of the river channel. A discrete water sample for measuring dissolved sulfide, and biochemical and chemical oxygen demand was collected 1-m above bottom depth for both lake and river stations. During August collections, a 24-hour diel sampling program was conducted at 3-hour intervals at lake stations and twice daily at river stations for selected parameters (Table A-3). Additionally, discrete water samples were collected at depth intervals of subsurface, 1 meter above the thermocline, 1 m below the thermocline and at 1 m above the lake bottom at Stations 1 through 8 during this period.

Whole-water samples were collected with Wildco 4.2-liter capacity PVC trace metal Kemmerer water sampling bottles. Sample preservation techniques recommended by the U.S. Environmental Protection Agency (EPA, 1979) were implemented immediately after sample collection. Parameters measured and their frequency of collection are listed in Table A-3. Analytical procedures and accuracy limits for water chemistry analyses are presented in Table B-1.

In situ measurements of temperature, conductivity, percentage light transmission, dissolved oxygen, pH and oxidation-reduction potential were profiled concurrently with the collection of water samples for lake and river stations. *In situ* parameters were measured with a Hydrolab System 8000. This system can measure temperature to within ±0.15°C, conductivity to within ±1 percent of range selected, dissolved oxygen to within ±0.2 mg/liter, pH to within ±0.15 units, and oxidation-reduction potential to within ±70 millivolts. Percentage light transmission was measured in the field with a Li-cor Integrating Quantum/Radiometer/Photometer (Model LI-188B) connected to a submersible Spherical Quantum Sensor (Model LI-1935). This system measures light intensity to within ±5 percent according to the manufacturer's specifications.

Sediment Sampling and Analysis

Sediment samples for pesticide, heavy metals and grain size determination were collected with an epoxy-coated Ponar dredge during April and September. At each lake station, a dredge sample was taken from shore to deep water substrate at each of three depths: littoral (shallow), 1 percent light transmittance level (mid-depth) and well below the 1 percent light transmittance level (deep). The three sediment samples then were combined into one composite sample. At each river station, four equally-spaced dredge samples were collected from shoreline to shoreline across the width of the river and then composited. All sediment samples were stored at 4°C in widemouth glass containers with Teflon-lined caps and extracted within seven days after collection. Analytical procedures and accuracy limits for measured parameters are listed in Table B-1.

Tissue Sampling and Analysis

Specimens of Asiatic clam (*Corbicula fluminea*), white catfish (*Ictalurus catus*) and largemouth bass (*Micropterus salmoides*) were collected at Stations 2, 4, 5, 7, 9 and 12 during April and September 1981. *Corbicula* were collected by hand, Ponar dredge or clam rake. Only adult *Corbicula* species of approximately 30 mm in shell length were collected at each station. White catfish and largemouth bass, ranging from 0.45 to 0.68 kg, were collected by fishing each station with gill nets, hoop nets, and hook and line. At least 5 individuals of each fish species and approximately 250 *Corbicula* were collected at each station. All specimens of each species were enclosed in polyethylene bags, placed on dry ice and kept frozen until analyzed. Analytical procedures and accuracy limits for tissue analysis are listed in Table B-1.

Quality Assurance and Control

The quality assurance and control program for chemical analyses is presented in Appendix A. These guidelines are followed as standard operating procedures by Applied Biology, Inc.

Statistical Analyses

Statistical analyses were performed according to procedures of the Statistical Analysis System (SAS; Helwig and Counsil, 1979). Data were transformed to $\log_e$ (number + 1) to reduce the effect of nonuniform variation and skewness in the data. Geometric and arithmetic means also were calculated. The General Linear Models (GLM) procedure was employed to give the regression approach to analysis of variance by using class variables to determine if an overall station, season or interaction effect was significant at the 0.1 percent level of determination. When an overall station or seasonal effect was significant, multiple range tests were performed by the Duncan procedure to determine significant differences in individual station means.

For some analyses, a sine or cosine transformation of elapsed time was used as an independent variable. This procedure reduces error variance from seasonal cycles of the dependent variable thereby increasing the power of the analysis. In regression analysis, the transformed elapsed time variable was included to isolate nonseasonal trends of the independent variable. The transformation of elapsed time was computed by one of the following algorithms:

SINADJ = Sine (2π/365 days x elapsed time);
or
COSADJ = Cosine (2π/365 days x elapsed time)

Where: Elapsed time is zeroed at 1 January.

Selection of the proper transformation was based on the trend of the dependent variable.

Data generated from the 1981 Clarks Hill Lake water quality study were coded and placed on the Environmental Protection Agency's STORET computer system. This system is used by various federal and state agencies for the storage and retrieval of data relating to the quality of the waterways within and contiguous to the United States.

RESULTS AND DISCUSSION

Water quality tabular data and results of statistical analyses are presented in Appendix Tables B-1 through B-165.

Temperature

Temperature patterns observed at Clarks Hill Lake were typical of warm monomictic lakes, which are characterized by large annual temperature variation and strong thermal gradients. Surface water temperatures ranged from 9.0°C in February to 32.0°C in June. The lowest temperature recorded was 6.5°C in 43 m of water at Station 1 in February. Temperature profiles at lake stations during February and October showed little variation among depths (Figure B-1 through B-10). These data indicate that Clarks Hill Lake begins winter mixing by late October and most likely continues through February.

Summer temperature stratification of Clarks Hill Lake was observed in June with the thermocline located at a depth of approximately 6 to 8 m. By August, the thermocline had dropped to a depth of 10 to 12 m at stations located in the main channel of the lake. Thermocline formation was less pronounced at Stations 5 and 8 where river flow resulted in water column mixing. Station 3, located in a cove off the main channel of the lake, did not display thermal stratification because of its relatively shallow depth ($\leq$4m).

Temperature profiles at Stations 11 and 12, located below Clarks Hill Dam in the Savannah River, reflected the hypolimnetic discharge of lake waters. For example, the surface temperature of tailwaters at Station 11 in June was 16.3°C. This corresponded to temperatures recorded at Station 1 at the face of the dam at a depth of approximately 17 m. Temperatures at Station 11 ranged from 7.7°C in February to 19.3°C in August. Temperatures observed at Station 12, located 4.8 km below the dam, were generally 1° to 2°C warmer than those recorded at Station 11. Temperature measurements at these stations were taken during periods of minimal release flow from Clarks Hill Dam. Temperatures at Station 10 in the Broad River were generally a few degrees less than ambient temperatures measured in the lake.

Dissolved Oxygen

Dissolved oxygen measurements at lake stations ranged from 0.2 mg/liter at a depth of 12 m at Station 5 in June to 11.4 mg/liter at a depth of 6 m at Station 1 in February. Dissolved oxygen values were similar among lake stations within sampling periods and depths but varied seasonally (Figure B-1 through B-10). Dissolved oxygen measurements in February were the highest observed during the study. The average measurement of dissolved oxygen in surface waters from the lake stations during February was 9.8 mg/liter. During this period when the lake was mixing, the oxygen content of the water varied only slightly from surface to bottom at lake stations. Dissolved oxygen measurements recorded below the dam at Stations 11 and 12 during February averaged 10.8 mg/liter.

Dissolved oxygen values in June and August displayed summer oxygen depletion at near-bottom depths with temperature stratification of the lake. Oxygen depletion was particularly noticeable at Stations 5 and 7 in the Georgia and South Carolina Little Rivers where dissolved oxygen measurements fell below 1.0 mg/liter below the thermocline. To support a well balanced aquatic fauna, the EPA's minimum criteria for dissolved oxygen is 5.0 mg/liter (EPA, 1976a). Insufficient dissolved oxygen in the water column promotes the anaerobic decomposition of any organic materials present. In addition, low dissolved oxygen concentrations will allow the reduction and subsequent leaching of iron and manganese from sediments into the water column. Results of analyses of whole-water samples showed significantly higher concentrations of iron and manganese at Stations 5 and 7 than at most other lake stations. The occurrence of oxygen depletion at Stations 5 and 7 during summer months suggests a strong oxygen consuming or reducing system that reaches anaerobic conditions below the thermocline.

The hydroelectric facility at Clarks Hill Dam draws off deep hypolimnetic waters from Clarks Hill Lake for electrical production. During summer periods, these deep waters may become depleted of dissolved oxygen when thermal stratification of the lake occurs. Lake waters discharged into the Savannah River at Station 11 below the dam during June and August had dissolved oxygen concentrations of 4.7 and 3.4 mg/liter, respectively. Little or no reaeration of dam release waters was observed at Station 12, approximately 5.0 km downstream of the dam during this period. Reaeration of release waters below hypolimnetic discharge reservoirs depends on the design of the outlet works, turbulence of flow in the tailwaters and extent of photosyntheses by aquatic vegetation below the dam (U.S. Army Corps of Engineers, 1982a). The stretch of the Savannah River below Clarks Hill Dam between Stations 11 and 12 had sparse populations of rooted aquatic vegetation along its banks and virtually no riffles or areas of high turbulence where atmospheric oxygen could be reintroduced into the water column. Also the severe lack of rainfall during 1981 restricted electrical production at the dam, reducing the volume of water being discharged into the river. A reduction in release flow would result in decreased turbulence below the dam. Dissolved oxygen concentrations most likely would be increased at the discharge point below the dam under normal operating conditions.

By late October, with winter mixing of the lake in progress, dissolved oxygen concentrations at lake stations were nearly homogeneous throughout the water column. Values ranged from 7.0 mg/liter at Station 7 in 10 m of water to 10.1 mg/liter at Station 4 in 6 m of water. The exception to this distribution was at Station 1, where oxygen depletion was observed at depths below 24 m, indicating incomplete mixing of the water column at this station. Dissolved oxygen levels below the dam were 6.4 mg/liter at Stations 11 and 12, respectively. Surface water measurement of dissolved oxygen at Station 10, in the Broad River, was 10.4 mg/liter during this period.

Alkalinity and Hardness

Alkalinity is a measure of the buffering capacity of the water. Commonly occurring materials in natural waters that increase the alkalinity are carbonates, bicarbonates, phosphates and hydroxides. Alkalinity measurements at Clarks Hill Lake ranged from 4.5 mg/liter at Station 8 to 22.0 mg/liter at Station 10 (Table B-2). Overall, Station 10 in the Broad River had the highest alkalinity with a mean value of 18.3 mg/liter. At lake stations, alkalinity concentrations at Stations 7, 5 and 1 were significantly greater than those recorded at Station 9. Below the dam, alkalinity concentrations at Station 12 were significantly greater than those at Station 11. Mean alkalinity values at Stations 11 and 12 were 11.8 and 13.5 mg/liter, respectively. The carbonate and bicarbonate buffering capacity of Clarks Hill Lake is low. The EPA (1976) criterion for alkalinity (as $CaCo_3$) is 20 mg/liter for freshwater aquatic life except where natural conditions are less. Alkalinity is important for fish and other aquatic life in freshwater systems because of its ability to buffer pH changes that occur naturally as a result of photosynthetic activity by algae and aquatic vegetation. The low buffering capacity of Clarks Hill Lake makes it susceptible to rapid fluctuations in pH.

Water hardness determinations at Clarks Hill Lake reflected the low calcium carbonate system. Hardness measurements ranged from 7.50 to 13.45 mg/liter. Waters at Clarks Hill Lake, based on classification by hardness content, are considered soft. Overall, Stations 7 and 5 had the highest hardness content of lake waters although no significant differences were found among stations.

pH

pH is the measure of the hydrogen ion activity in water. pH is an important factor in the chemical and biological systems of natural waters because changes in pH affect the degree of dissociation of weak acids and bases which, in turn affects the degree of toxicity of many organic and inorganic compounds. The pH values measured at Clarks Hill Lake during the 1981 water quality study ranged from 4.38 to 9.54. Lake profiles taken during February, June, August and October showed that pH values varied with depth and season (Figures B-1 through B-10).

As with temperature and dissolved oxygen, pH variation among stations and depths was minimal during periods of lake mixing. Values measured in February and October at lake and river stations ranged from a pH of 6.06 to 6.75 and 5.59 to 6.69, respectively. However, pH values during summer thermal stratification of the lake generally decreased with water depth. Reductions in pH with depth were concomitant with reductions in temperature, dissolved oxygen and oxidation reduction potentials. Values in August ranged from a pH of 4.38 at Station 1 in 24 m of water to 9.54 at Station 8 in 1 m of water. Diel profiles of pH values recorded in August did not show significant variation within depths over time. Differences in pH between epilimnion and hypolimnion waters most likely resulted from the interaction of various oxidation and reduction processes in conjunction with the low buffering capacity of the water. Variation in pH in upper hypolimnion waters between collection periods most likely resulted from photosynthetic activity by algae.

Comparison of pH values from the 1973 EPA study of Clarks Hill Lake and of those observed during 1981 indicate a reduction in the mean pH of the lake (Table B-3). Also, the range of pH values observed has increased from 5.6 to 8.3 in 1973 to 4.38 to 9.54 in 1981. Differences in pH means and ranges between study years most likely resulted from variations in sampling techniques and intensity of study design. However, because Clarks Hill Lake has a low buffering capacity, fluctuations in pH values would be expected over time. The pH of Clarks Hill Lake waters are similar in range to those observed from other southeastern reservoirs and lakes (ESE, 1981).

Free Carbon Dioxide

Free carbon dioxide (CO_2) content of the water is the surplus amount of CO_2 available to stabilize calcium bicarbonate in solution. Surface waters normally contain less than 10 mg/liter free carbon dioxide. Free carbon dioxide values ranged from 0.10 mg/liter to 8.83 mg/liter. Of the lake stations, Station 1 had the highest mean free CO_2 content with 3.96 mg/liter and Station 8 was lowest with a value of 0.95 mg/liter. Stations 11 and 12, below Clarks Hill Dam, had a mean free CO_2 content of 4.53 and 4.79 mg/liter, respectively. Statistical comparisons of free CO_2 values showed no significant differences among lake or river stations.

Conductivity

Conductivity is a measure of the dissociated ions in water. Measured conductivity values depend on two factors: the total concentration of the ionized substances dissolved in a sample of water and the temperature of the water sample. Conductivity at Clarks Hill Lake varied by station, depth and season. Generally, values were lowest in winter months and highest in summer months. October measurements were intermediate. Conductivity values ranged from 50 to 140 μmhos/cm at lake stations and from 20 to 120 μmhos/cm at river stations. Conductivity measurements at Stations 5 and 7 in the Georgia and South Carolina Little Rivers typically displayed the widest range of values recorded. During the periods of lake mixing in February and October, only slight differences in conductivity were recorded at various depths. However, when the lake was stratified during June and August, conductivity measurements decreased with depth with a noticeable decrease usually occurring at the thermocline. A significant amount of diel variation in conductivity with depth was observed in August. Conductivity ranges at Clarks Hill Lake are generally higher than those observed at Lake Hartwell or Lake Sidney Lanier, where a range of 30 to 40 μmhos/cm was observed (ESE, 1981).

Oxidation-reduction Potential

The oxidation-reduction potential, or redox, is a measure of the oxidizing or reducing potential of water. Redox is influenced by various parameters, such as temperature, pH, oxygen content and the amount of dissolved materials in the water. The redox potential of Clarks Hill Lake varied by station, depth and season. Redox potentials ranged from -40 mv at Station 7 in 11 m of water to +507 mv at Station 1 in 24 m of water during August diel profiles. Typically, redox potentials increased with water depth down to near bottom levels where a decrease in redox potential occurred at the water-mud interface. However, during summer stratification of the lake, a decrease in redox potential was also observed at or just below the thermocline. Stations 5 and 7 showed significant decreases in redox potentials below the thermocline during summer profiles of the water column. The redox potential was lowered at these stations when pH, temperature and oxygen content decreased and conductivity increased. The lowered redox potentials at Stations 5 and 7 give further evidence of a strong reducing system below the thermocline at these stations during summer periods.

Biochemical Oxygen Demand, Chemical Oxygen Demand and Total Organic Carbon

Biochemical oxygen demand (BOD) is the measure of the relative oxygen requirements of water. Chemical oxygen demand (COD) is a determination of the oxygen equivalent of that portion of a water sample's organic matter that is susceptible to oxidation by a chemically defined dichromate solution. Both of these tests, as well as that for total organic carbon (TOC), indicate the concentration of organic material present in water and can be used as a measure of water quality. BOD values for lake stations ranged from 2.0 to 7.5 mg/liter, COD values ranged from 5.0 to 34.5 mg/liter and TOC values ranged from 1.0 to 8.5 mg/liter (Table B-2). Statistical comparison of data for these parameters showed no significant differences among lake stations for BOD and TOC measurements. However, comparison of COD values showed that Stations 2 and 4 had significantly greater chemical oxygen demand than Stations 3 and 8. At river Stations 10, 11 and 12, values for these parameters fell within the range of those observed at lake stations. No significant differences were found among river stations in BOD, COD or TOC content. Overall measured values for these parameters show that Clarks Hill Lake does not contain high levels of organic materials in the water column. However, with the construction of the Richard B. Russell hydroelectric facility on the Savannah River above Clarks Hill Lake, the water quality near Station 9 may be altered. Release waters from this facility would most likely be high in organic debris and suspended particulate matter during early phases of operation. An initial increase in turbidity, BOD, COD and TOC levels and a decrease in light penitration would be anticipated downstream of the dam.

Phosphorus and Nitrogen

Phosphorus and nitrogen are two of the major nutrients required for plant nutrition. However, high concentrations of these nutrients are often associated with eutrophic waters. Phosphorus at Clarks Hill Lake was measured in the forms of total phosphate and orthophosphate. Nitrogen was measured in the forms of nitrate-nitrite nitrogen, ammonia nitrogen and organic nitrogen.

Total Phosphate

Although no criterion has been established, the EPA (1976a) has recommended that total phosphates as phosphorous (P) should not exceed 0.050 mg/liter in any stream at the point where it enters any lake or reservoir, nor 0.025 mg/liter within the lake or reservoir. The mean phosphate concentration recorded at Clarks Hill Lake stations exceeded these recommended limits, with the exception of Stations 1 and 2 (Table B-2). Total phosphate measurements ranged from <0.010 to 0.515 mg/liter. Although no significant differences were found among stations, mean phosphate concentrations from tributaries were higher than those observed from lake stations (Figure B-11). Total phosphate concentration was highest at Station 5 in the Georgia Little River where phosphorous levels have increased 550 percent since 1973 (Table B-4). Total phosphate concentrations in the South Carolina Little River (Station 7) and Savannah River (Station 9) each showed a percentage change of +112 percent, while the Broad River (Station 8) has shown a +37 percentage change since 1973. During the 1973 EPA eutrophication survey at Clarks Hill Lake, tributaries entering the system accounted for over 76 percent of the lake's total phosphorus, equating to approximately 343,500 kg of phosphorus per year (EPA, 1976b). The Savannah and Broad Rivers and the Georgia and South Carolina Little Rivers accounted for 32.8, 25.2, 7.8 and 4.3 percent of the total phosphorus in the lake, respectively, during this period.

Total phosphate concentrations at Station 10 in the upper Broad River ranged from 0.055 to 0.145 mg/liter with an overall mean value of 0.092 mg/liter during 1981. Measurements below Clarks Hill Dam at Stations 11 and 12 ranged from <0.010 to 0.045 mg/liter. Total phosphate concentrations observed at Clarks Hill Lake are similar to those found in other southeastern reservoirs and lakes. Lake Hartwell, located at the upper end of the Savannah River, and Lake Sidney Lanier in north central Georgia each had total phosphate levels which also exceeded the EPA recommended maximum criterion for this parameter (ESE, 1981; Army Corps of Engineers, 1982).

Phosphates enter the aquatic environment through a variety of sources. Agricultural runoff and industrial and domestic wastewaters are but a few. Once this nutrient enters an aquatic environment such as Clarks Hill Lake it may be dispersed into bottom sediments or utilized by algae and other aquatic plants for growth. Excessive algal growth can become aesthetically unpleasant and alter the quality of the water supply and they contribute to the phenomenon of cultural eutrophication (EPA, 1976a). Eutrophy is a term that is broadly applied to aquatic environments where nutrient levels become capable of supporting a rich organic production. Eutrophication is a natural progression of lake or reservoir ageing. However, rates of eutrophication can become accelerated when high concentrations of nutrients are introduced into aquatic systems. Phosphate concentrations at Clarks Hill Lake are continuing to increase over time. The presence of several species of algae and macroinvertebrates associated with eutrophic habitats suggest that nutrients concentrations in the lake may be reaching levels capable of supporting a rich organic production. Low periphyton diversity and predominance of the diatom species, *Achnanthes minutissima* may reflect environmental stress caused by phosphate loading at Station 5 (Section G).

Orthophosphate

Orthophosphate is generally considered the most utilizable form of phosphorous for algae and aquatic vegetation. It is the product of microbial degradation of organic phosphates and of hydrolysis of condensed phosphates.

Orthophosphate concentrations measured at lake and river stations were less than detectable limits (<0.01 mg/liter) throughout most of the study. A value of 0.08 mg/liter was recorded in one replicate at Station 1 in February. The only other observed value for orthophosphate that was above detection limits occurred at Station 10 in October when a concentration of 0.02 mg/liter was recorded. Generally, orthophosphate can be considered as a limiting nutrient when concentrations are below 0.01 mg/liter. The lack of detectable quantities of orthophosphate in Clarks Hill Lake suggest that primary productivity may be limited throughout most of the year. This concurs with findings of the EPA eutrophication survey conducted in 1973 at Clarks Hill Lake (EPA, 1976b). Although orthophosphate levels were typically low, sampling design may have biased the results of chemical analyses. Typically, during summer stratification, orthophosphate concentrations increases below the thermocline at those stations where anaerobic conditions prevail. However, composite water samples representing the entire water column most likely would not reflect increased orthophosphate amounts from hypolimnion waters. Also, available orthophosphate concentrations may have been bound up or utilized by algae and other aquatic plants. Generally, phytoplankton standing crop and chlorophyll-*a* levels were higher at tributary stations in comparison to lake stations.

Nitrate-nitrite Nitrogen

In oxygenated natural water systems, nitrite nitrogen is rapidly oxidized to nitrate nitrogen. Nitrate is a major nutrient for vegetation and an important trace element for most aquatic life. Nitrate-nitrite concentrations observed at Clarks Hill Lake ranged from <0.001 mg/liter at Station 3 to 1.051 mg/liter at Station 4. These values are well below the EPA maximum criterion of 10 mg/liter for domestic water supplies. Mean inorganic nitrogen concentrations were generaly below 0.3 mg/liter (Table B-2). Based on data form Wisconsin lakes, Allen & Kramer (1972) suggested that 0.015 mg/liter of inorganic phosphorus and 0.3 mg/liter inorganic nitrogen at spring maximum are critical levels above which algae blooms could be expected. Orthophosphate and nitrite-nitrate nitrogen ratios at Clarks Hill Lake are below this proposed guideline.

There were no significant differences among lake or river stations in nitrate-nitrite concentrations during the 1981 study period. the overall mean nitrate-nitrite nitrogen concentration for Clarks Hill Lake during 1981 was 0.166 mg/liter compared to 0.253 mg/liter in 1973.

Ammonia Nitrogen

Ammonia nitrogen is an active compound present in most waters as a biological degradation product of nitrogenous organic matter. Agricultural sources of ammonia volatilized from cattle feed lots has been shown to contribute significantly to the nitrogen budgets of downstream lakes. Ammonia toxicity varies with the pH and temperature of the water. Levels of un-ionized ammonia (NH_3) in the range of 0.20 to 2 mg/liter have been shown to be toxic to some species of freshwater aquatic life. A criterion of 0.02 mg/liter NH_3 is established as the maximum acceptable value for maintenance of freshwater life (EPA, 1976a). Ammonia nitrogen values at Clarks Hill Lake ranged from <0.01 to 0.67 mg/liter. Mean NH_3 values at all lake stations exceeded the EPA recommended limit (Table B-2). No significant differences in ammonia nitrogen concentration among stations were shown. Ammonia nitrogen concentration in Clarks Hill Lake has decreased since the 1973 EPA study from a mean value of 0.248 mg/liter to 0.073 mg/liter observed in 1981.

Organic Nitrogen

Organic nitrogen values (total Kjeldahl nitrogen) ranged from 0.16 to 2.76 mg/liter at lake stations and from 0.12 to 3.15 mg/liter at river stations. The highest mean TKN concentration was observed at Station 12 in the Savannah River (Table B-2, Figure B-13). No significant differences in TKN values were observed among stations.

Dissolved Sulfide, Hydrogen Sulfide and Total Sulfate

Concentrations of dissolved sulfide and un-ionized hydrogen sulfide (H_2S) at lake and river stations never exceeded the 0.05 mg/liter detection limit for these parameters. Total sulfate values were highest at tributary stations with the maximum concentration of 24.0 mg/liter recorded at Station 5. Total sulfate concentrations did not differ significantly among stations. Little or no diel variation in sulfate concentrations was observed in August.

Other Chemical Parameters

Turbidity concentrations observed at Clarks Hill Lake reflected differences in station locations. Generally, turbidity measurements at riverine stations were higher than at lake stations. However, no significant variation in turbidity measurements was shown among stations. Mean turbidity values ranged from 33.4 mg/liter at Station 7 to 4.7 mg/liter at Station 1 (Table B-2).

Color units measured at Clarks Hill Lake ranged from 10 to 70. Criteria for color established by the EPA (1976a) recommends that domestic water supplies should not exceed 75 color units. Generally, color in water results from degradation processes and is pricipally of aesthetic value. Color at Stations 1 and 6 was significantly lower than at other tributary or lake stations. Color units in the Savannah River below Clarks Hill Dam were similar to those observed at Station 1 (Table B-2).

Residue, total filterable and nonfilterable refers to solid matter suspended or dissolved in the water. Residue concentrations from Clarks Hill Lake were generally low, not exceeding 100 mg/liter. A limit of 500 mg/liter is desirable for drinking water. No significant differences in residue concentrations were shown among stations.

Pesticide Analysis

Determinations of various pesticide concentrations in sediment samples and from the tissues of the Asiatic clam (*Corbicula fluminea*), white catfish (*Ictalurus catus*) and largemouth bass (*Micropterus salmoides*) showed no apparent contamination or biomagnification of these parameters at Clarks Hill Lake. Pesticide concentrations consistently were recorded as less than the detectable limit of 1.0 μg/kg. In comparison to other southeastern reservoirs PCB analyses of fish collected from areas of Lake Hartwell during 1980 exceeded the FDA recommended maximum level of 5.0 ppm for fish flesh sold in interstate commerce (Army Corps Engineers, 1982b). Also, trace amounts of metabolites of DDT and PCB were detected in sediments and tissues from Lake Sidney Lanier during a recent study (ESE, 1981).

Metals Analyses Sediments

Chromium - Chromium in sediment samples from Clarks Hill Lake ranged from 7.50 to 35.00 mg/kg. Station 8 in the Broad River had the highest mean concentration of chromium with 29.35 mg/kg and Station 1 was lowest with 17.94 mg/kg. Chromium values at river stations were typically lower in comparison to lake stations. No significant station differences in chromium values in sediments were found. Results of statistical comparisons of heavy metal analyses in sediments are presented in Appendix Tables B-120 through B-133.

Copper - Copper values at Station 5 were significantly greater than those observed at most other stations. The reasons for the higher copper values at Station 5 are not known. Mean copper concentrations ranged from 3.06 mg/kg at Station 12 to 41.74 mg/kg at Station 5. The range of these values are similar to those observed from sediment samples from other regional studies (Army Corps Engineers, 1978).

Iron - The quantity of iron in sediments depends on the geology of the area, physicochemical components of the waterways and pollutants. Iron concentrations in sediments at Clarks Hill Lake are typical of those found in clay soils, where it is a major constituent (ESE, 1981; Army Corps of Engineers, 1982b). Total iron concentrations ranged from 12,063 to 38,148 mg/kg at lake stations and from 1688 to 33,542 mg/kg at river stations. Overall, Station 8 had the highest mean iron concentration, although no significant station differences were shown.

Manganese - Manganese does not occur naturally as a metal but it is found in various salts and minerals, frequently in association with iron compounds. Manganese from Clarks Hill Lake sediments were highest at tributary stations. Mean concentration of manganese ranged from 427.27 mg/kg at Station 12 to 968.51 mg/kg at Station 8. No significant differences in total manganese concentrations were found among lake or river stations.

Mercury - Mercury levels in sediments were fairly consistent among stations and no significant differences were found. Concentrations ranged from <0.005 to 0.063 mg/kg. The highest observed values were recorded at Stations 3 and 4.

Lead - Lead exists in nature mainly as lead sulfide. Lead enters the aquatic environment through erosion and leaching of soil, municipal and industrial waste discharges and through precipitation. The mean concentration of lead in sediments at Clarks Hill Lake was highest at Station 8 in the Broad River with 43.32 mg/kg followed by Station 5 in the Georgia Little River with 31.09 mg/kg. The minimum and maximum values recorded during the study were <0.10 mg/kg at Stations 1 and 12 and 50.00 mg/kg at Station 8. However, no significant differences in lead concentrations were found among stations.

Nickel - Nickel distribution in bottom sediments at Clarks Hill Lake was not significantly different among stations. Mean concentrations ranged from 2.67 mg/kg at Station 11 to 21.45 mg/kg at Station 8. Ranges of nickel concentrations observed at Clarks Hill were within the range of those recorded at Lake Seminole (Army Corps Engineers, 1978).

Zinc - Zinc concentrations were generally greater at tributary stations than in main lake stations although no significant station differences were found. Station 8 had the highest recorded mean zinc concentration, with 41.97 mg/kg followed by Station 9 with 40.77 mg/kg. Zinc concentration at Station 11 was significantly greater than at Station 12. Mean concentrations of zinc at Stations 11 and 12 were generally 3 to 4 times less than those observed at lake stations.

Arsenic - Arsenic compounds are fairly ubiquitous in nature, being found in most soil and water samples. Arsenic in sediments at Clarks Hill ranged from 0.86 mg/kg at Station 12 to 38.73 mg/kg at Station 8. Station 1 had the second highest recorded arsenic value with 28.87 mg/kg. No significant station differences were found for this parameter.

Cadmium - Cadmium in sediment samples at Clarks Hill Lake were less than the detectable limit of 0.05 mg/kg for all stations.

Metals Analyses-Tissues

Chromium - Chromium concentrations in the tissues of the Asiatic clam (*Corbicula fluminea*), the white catfish (*Ictalurus catus*) and the largemouth bass (*Micropterus salmoides*) were significantly higher at Station 4 than at most other lake or river stations. Chromium values ranged from 0.230 to 0.858 mg/kg in *Corbicula*, <0.010 to 0.796 mg/kg in white catfish and <0.010 to 0.158 mg/kg in largemouth bass. Statistical results of metal analyses in tissue samples are presented in Appendix Tables B-135 through B-151.

Mercury - Mercury in *Corbicula* tissue ranged from <0.001 mg/kg at all stations in September to 0.370 mg/kg at Station 9 in April. Overall, Station 9, in the Savannah River at the upper end of the reservoir, had significantly greater mercury levels in *Corbicula* tissues than the other sampling stations. The presence of mercury in *Corbicula* tissue in April may have resulted from uptake during periods of lake mixing when bottom sediments became disturbed. However, by September, *Corbicula* tissues showed no sign of mercury contamination, suggesting that it had been eliminated through excretion. Mercury concentrations in the tissues of the white catfish and largemouth bass were below detectable limits of <0.001 mg/kg for all stations during the April and September collection periods.

Zinc - Zinc in Corbicula and largemouth bass tissues showed no significant differences among stations. However, zinc in the white catfish was significantly greater at Stations 4 and 5 than at Stations 2, 7 or 9. Corbicula tissues had the highest zinc concentrations with a mean of 11.70 mg/kg compared to 4.20 and 4.08 mg/kg for the white catfish and largemouth bass, respectively.

Arsenic - Arsenic concentrations followed the same pattern of distribution as the previous heavy metals in that Corbicula tissues were highest in arsenic followed by white catfish and largemouth bass. Arsenic in Corbicula tissues at Station 4 were significantly greater than those observed for other lake stations. Concentrations of arsenic in Corbicula ranged from 0.024 to 0.613 mg/kg, with an overall mean of 0.347 mg/kg. These values are lower than those observed in the Lake Seminole study. Arsenic in the white catfish was significantly greater at Stations 5 and 7 than at Station 4. The mean concentration of arsenic in white catfish tissue collected from Clarks Hill Lake was 0.305 mg/kg, with a range of <0.010 to 0.677 mg/kg. Arsenic in largemouth bass tissue ranged from <0.010 mg/kg at all stations in September to 0.594 mg/kg at Station 4 in April. The mean arsenic concentration in largemouth bass tissue was 0.284 mg/kg. No significant differences in arsenic concentrations were observed among stations for this species.

Cadmium - Cadmium measurements in tissue analyses varied by species and station. Cadmium in Corbicula tissues at Station 2 was significantly greater than in those collected at Stations 5 or 7. Observed levels of cadmium in Corbicula tissues ranged from <0.100 to 0.243 mg/kg. White catfish at Station 9 had significantly greater cadmium concentrations than in those collected at Stations 2, 4, 5 or 7. No significant station differences were observed for cadmium found in the tissues of the largemouth bass. Mean cadmium concentrations in the tissues of Corbicula, white catfish and largemouth bass were 0.136, 0.167 and 0.199 mg/kg, respectively.

Lead - Lead in tissue samples was generally highest at Station 5 in the Georgia Little River where high amounts were also found in sediments. No significant differences were observed among lake stations for lead concentrations in the tissues of Corbicula or the largemouth bass. Lead found in the white catfish was significantly higher at Stations 4 and 5 than at Stations 2, 7 or 9. Mean lead values in Corbicula at lake stations ranged from 1.462 to 4.063 mg/kg, white catfish values ranged from 1.880 to 2.759 mg/kg, and largemouth bass values for lead ranged from 1.120 to 3.155 mg/kg.

Selenium - Selenium values in tissue analyses were less than the detectable limit of 0.001 mg/kg. The only exception to this was Corbicula tissues collected during September. During this period, mean selenium concentrations in the Asiatic clam ranged as high as 0.301 mg/kg at Station 5.

Metals Analyses-Whole-Water Samples

Iron - Iron is an essential trace element required by both plants and animals. However, iron can become toxic to freshwater aquatic life and may be a limiting factor for the growth of algae and other plants when found in high concentrations. The EPA (1976a) maximum criteria for total iron is 1.0 mg/liter. Mean iron concentrations from whole water samples collected at Clarks Hill Lake Stations 3, 5, 7, 8, 9 and 10 exceeded the recommended limit for this parameter. Iron concentrations at these stations were significantly greater than those observed at Stations 1, 2 and 6. Mean iron values ranged from 0.45 mg/liter at river Station 12 to 2.62 mg/liter at Station 10 in the Broad River. Results of statistical evaluation of heavy metals analyses in whole water samples are presented in Appendix Tables B-151 through B-164. Iron concentrations were generally highest in February when the lake was mixing. High iron levels in Clarks Hill Lake waters esults from the high concentration of iron in the clay soils of the surrounding area. Iron is also leached from the bottom sediments and resuspended in the water column when diminished oxygen levels occur below the thermocline.

Manganese - Manganese is a micro-nutrient vital for both plants and animals. The maximum criterion for manganese in domestic water supplies is 0.050 mg/liter (EPA, 1976a). Mean total manganese concentrations at Clarks Hill Lake stations exceed this limit with the exception of Stations 1 and 6. Overall, Stations 5 and 7 in the Georgia and South Carolina Little Rivers had significantly greater manganese concentrations than other lake stations. As with iron, this most likely results from the leaching of manganese from sediments at the water bottom interface where low oxygen conditions prevails. The minimum and maximum manganese values ranged from <0.010 mg/liter at Stations 1, 3, 6, 11 and 12 to 0.262 mg/liter at Station 5.

Calcium - Calcium distribution in whole water samples from Clarks Hill Lake ranged from 0.61 to 3.14 mg/liter. Mean calcium values were lowest at Station 3 (1.14 mg/liter) and highest at Stations 1 and 7 (2.50 mg/liter). Calcium concentrations were significantly higher at Station 1 than at Stations 8, 4 or 3. The generally low calcium values observed at Clarks Hill Lake reflect the low buffering capacity of the system.

Potassium - Potassium concentrations did not vary greatly among lake stations. Mean values ranged from 1.29 mg/liter at Station 1 to 1.75 mg/liter at Station 4. Potassium concentrations below the dam at Stations 11 and 12 were slightly lower than those observed at lake stations. The highest potassium content in whole-water samples was recorded at Station 10 in the Broad River, which had a maximum value of 4.75 mg/liter.

Sodium - Sodium content of natural waters varies from less than 1 mg/liter in rainwater to very high levels found in brines of closed basins where more than 100,000 mg/liter may be present. The sodium content of waters at Clarks Hill Lake is fairly low, with mean values ranging between 4.42 to 8.85 mg/liter. Sodium concentrations were significantly higher at Station 5 than at most other lake or river stations.

Trophic Condition

Characterization of aquatic environments in reference to trophic condition has received much attention in recent years. However, definition of terms applied to trophic evaluations of freshwater streams and lakes often are not consistent among classification regimes. For purposes of conformity, the trophic condition of Clarks Hill Lake will be partially based on the classification as defined by Wetzel (1975).

1. Eutrophic: characteristic of water with high nutrient concentrations.
2. Mesotrophic: characteristic of water with moderate nutrient concentrations.
3. Oligotrophic: characteristic of water with low nutrient concentrations.
4. Dystrophic: characteristic of waters rich in humic material.

The overall trophic condition of Clarks Hill Lake is considered mesotrophic, a characteristic of waters with moderate nutrient concentration. However, because Clarks Hill Lake is a large body of water with many tributaries entering it, the trophic status of its major source water systems must be considered separately. The Savannah and Broad River and the Georgia and South Carolina Little Rivers are major input sources of phosphate in Clarks Hill Lake. Phosphate concentrations at tributary stations have increased since the 1973 eutrophication survey at Clarks Hill Lake. Total phosphate concentration was highest at Station 5 in Georgia Little River where phosphorous levels have increased 550 percent since 1973. Although primary productivity may be limited as a result of low concentrations of orthophosphate and nitrate-nitrite levels, phytoplankton densities and chlorophyll-a concentrations at tributary stations were considerable higher in comparison to lake stations. The progressive decrease in standing crop from these tributaries to the dam corresponded to the distribution of total phosphate within the lake and reflected the continued influence of nutrient enrichment in these areas. Overall, eutrophy is indicated at Stations 5 and 7 in the Georgia and South Carolina Little Rivers, respectively, and at Stations 8 and 10 in the Broad River and Station 9 in the upper Savannah River. Stations 1, 2, 3, 4 and 6 in Clarks Hill Lake and Stations 11 and 12 below the dam on the lower Savannah River are considered mesotrophic. Evaluations of trophic condition in Clarks Hill Lake and tributary waters made during the 1981 water quality study are in general agreement to those found during the 1973 eutrophication survey conducted by the Environmental Protection Agency at Clarks Hill Lake.

SUMMARY

During the 1981 water quality study at Clarks Hill Lake composite whole-water samples were collected at eight lake and four river stations during February, June, August and October. In August, a 24-hour diel sampling program was conducted at 3-hour intervals at lake stations and twice daily at river stations for selected parameters. In situ measurements of temperature, conductivity, dissolved oxygen, pH, oxidation-reduction potential and percentage light tramsmission were profiled concurrently with the collection of water samples. In addition, sediment and tissues of the Asiatic clam (*Corbicula fluminea*), white catfish (*Ictalurus catus*) and largemouth bass (*Micropterus salmoides*) were collected during April and September and analyzed for pesticice and heavy metal content.

Clarks Hill Lake is characteristic of warm monomictic lakes with large annual variation in temperature and development of strong thermal gradients during summer stratification periods. Thermal stratification of the lake was observed in June with the thermocline located at a depth of 6 to 8 m. By late August, the thermocline had lowered to a depth of 10 to 12 m at most lake stations. During this period depletion of dissolved oxygen in deep hypolimnion waters occurred, particularly at stations located in the Georgia and South Carolina Little Rivers where dissolved oxygen measurements were recorded as less than 1.0 mg/liter below the thermocline. Reduction and subsequent leaching of iron and manganese from bottom sediments resulted in significantly higher concentrations of these parameters in the water column where anaerobic conditions prevailed. Reductions in pH and oxidation reduction potentials were concomitant with reductions in dissolved oxygen concentrations at these stations.

The hydroelectric facility at Clarks Hill Dam draws hypolimnetic waters from the lake for electrical production. During summer periods these deep waters become depleted of dissolved oxygen when thermal stratificaton of the lake occurs. Lake waters discharged into the Savannah River below the dam during this period had dissolved oxygen values below the EPA recommended minimum of 5.0 mg/liter. However, the severe lack of rainfall during 1981 restricted electrical production at the dam, reducing the volume of water being dicharged into the river. Reduced flow resulted in decreased turbulence in tailwaters and subsequent lack of adequate reaereation of discharge waters. However, by late October, with winter mixing of the lake in progress, dissolved oxygen and other physicochemical parameters showed a nearly homogeneous distribution through the water column. Winter mixing or turnover of Clarks Hill Lake most likely continues until sometime in March or April.

Clarks Hill Lake waters are soft and have a low carbonate, bicarbonate buffering capacity. As a result, fluctuations in pH between epilimnion and hypolimnion waters occurred from the interactions of various oxidation and reduction processes.

Clarks Hill Lake has a relative low organic base with primary productivity limited throughout most of the year by orthophosphate and nitrate-nitrite nitorgen levels. However, phosphate levels in Clarks Hill Lake exceed recommended concentrations suggested by the EPA Quality Criteria for Water. Tributaries such as the Georgia and South Carolina Little Rivers and Savannah and Broad Rivers are major sources of input of phosphorus in Clarks Hill Lake. However, although total phosphate concentrations are high, they are within the range of those observed in other southeastern reservoirs and lakes.

Determinations of varous pesticide concentrations in sediments and tissue samples from Corbicula, white catfish and largemouth bass showed no apparent contamination or biomagnification of these parameters at Clark Hill Lake. Analyses of heavy metals in sediments, tissues and whole-water samples generally showed higher concentrations of these parameters at tributary stations in comparison to lake stations. No consistent trends in heavy metal distribution were observed among stations.

The overall trophic condition of Clarks Hill Lake is considered mesotrophic, characteristic of waters with moderate nutrient concentrations. However, evaluation of major tributary waters entering the lake suggest that the Georgia and South Carolina Little Rivers as well as the Broad and upper Savannah Rivers are eutrophic. This assessment is in general agreement with the 1973 eutrophication survey conducted at Clarks Hill Lake by the EPA.

LITERATURE CITED

Allen, H.E. and J.R. Kramer. 1972. Nutrients in natural waters. John Wiley & Sons, New York. 457 pp.

Army Corps of Engineers, Water Quality Management Studies. 1978. Report on Lake Seminole (April-November). Technical Report ACF 80-1.

Army Corps of Engineers. 1982a. Environmental and Water Quality Operational Studies. Vol. E-82-2. pp 1-5.

Army Corps of Engineers. 1982b. Personal Communications. Dr. Thomas Rennie, Savannah District Army Corps of Engineers.

EPA (Environmental Protection Agency). 1976a. Quality criteria for water.

EPA (Environmental Protection Agency) National Eutrophication Survey. 1976b. Report on Clark Hill Reservoir. Working Paper No. 287.

EPA (Environmental Protection Agency). 1979. Methods for chemical analysis of water and wastes. EPA-60014-79-020.

ESE (Environmental Science and Engineering, Inc.) 1981. Water Quality Management Study Lake Sidney Lanier. Prepared for U.S. Army Corps of Engineers, Mobile District. Volumes I-IV.

Helwig, J.T. and K.A. Counsel, ed. 1979. SAS user's guide. SAS Institute, Inc., Raleigh, NC. 494 pp.

Wetzel, R.G. 1975. Limnology. W.B. Sanders Co. Philadelphia, PA. 743 pp.

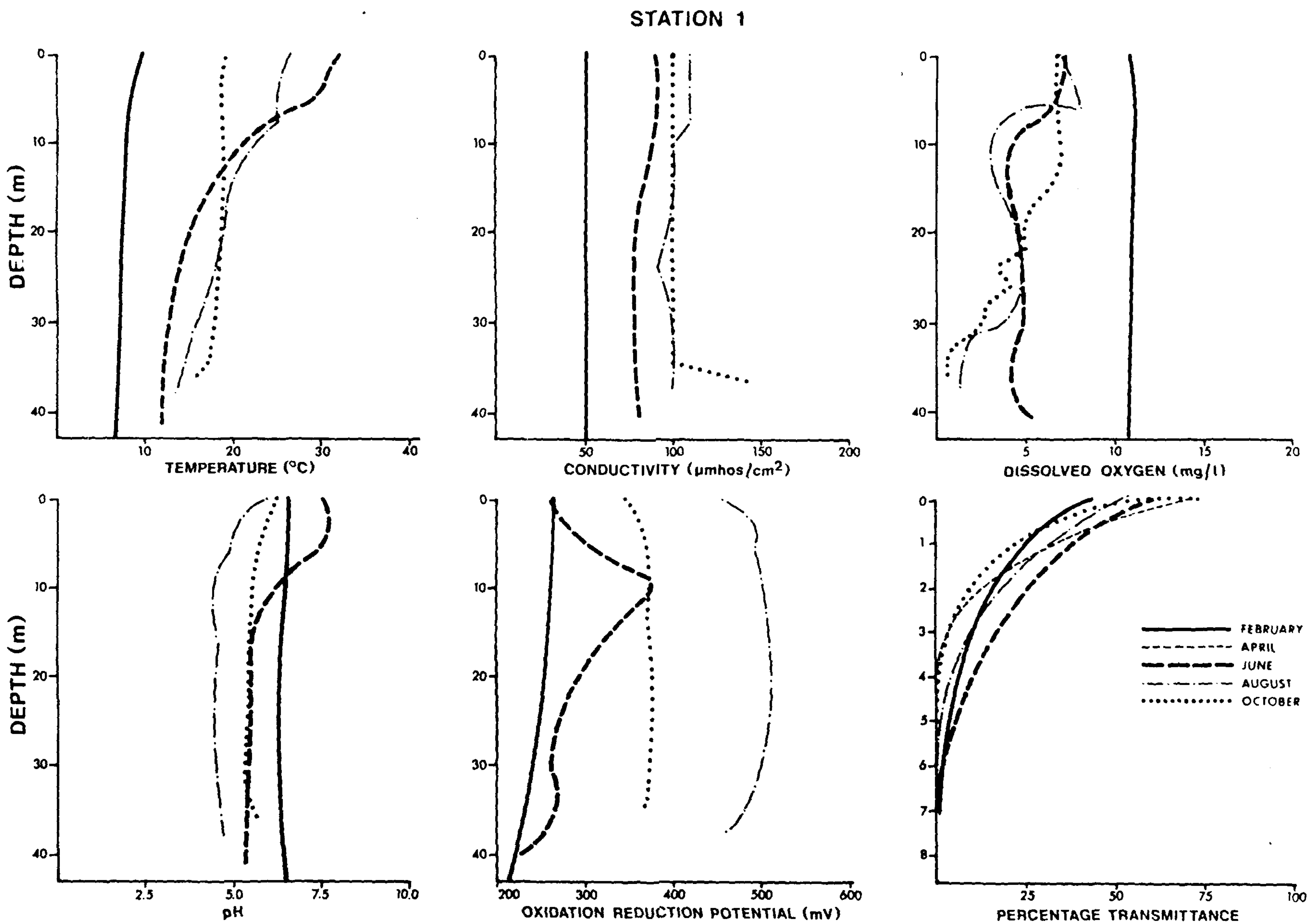


Figure B-1. Summary of *in situ* measurements by depth and month, Station 1, Clarks Hill Lake, February-October 1981.

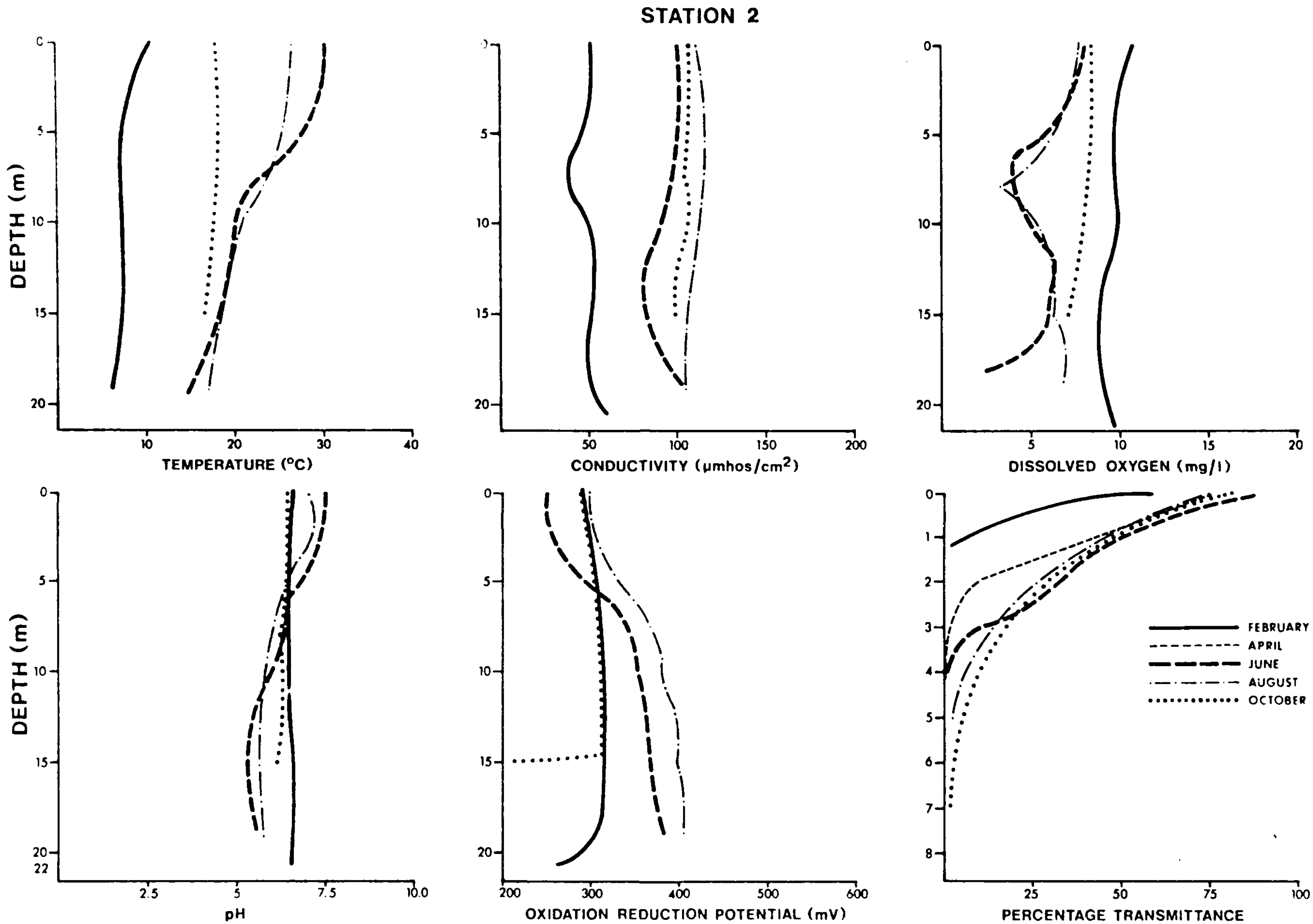


Figure B-2. Summary of *in situ* measurements by depth and month, Station 2, Clarks Hill Lake, February-October 1981.

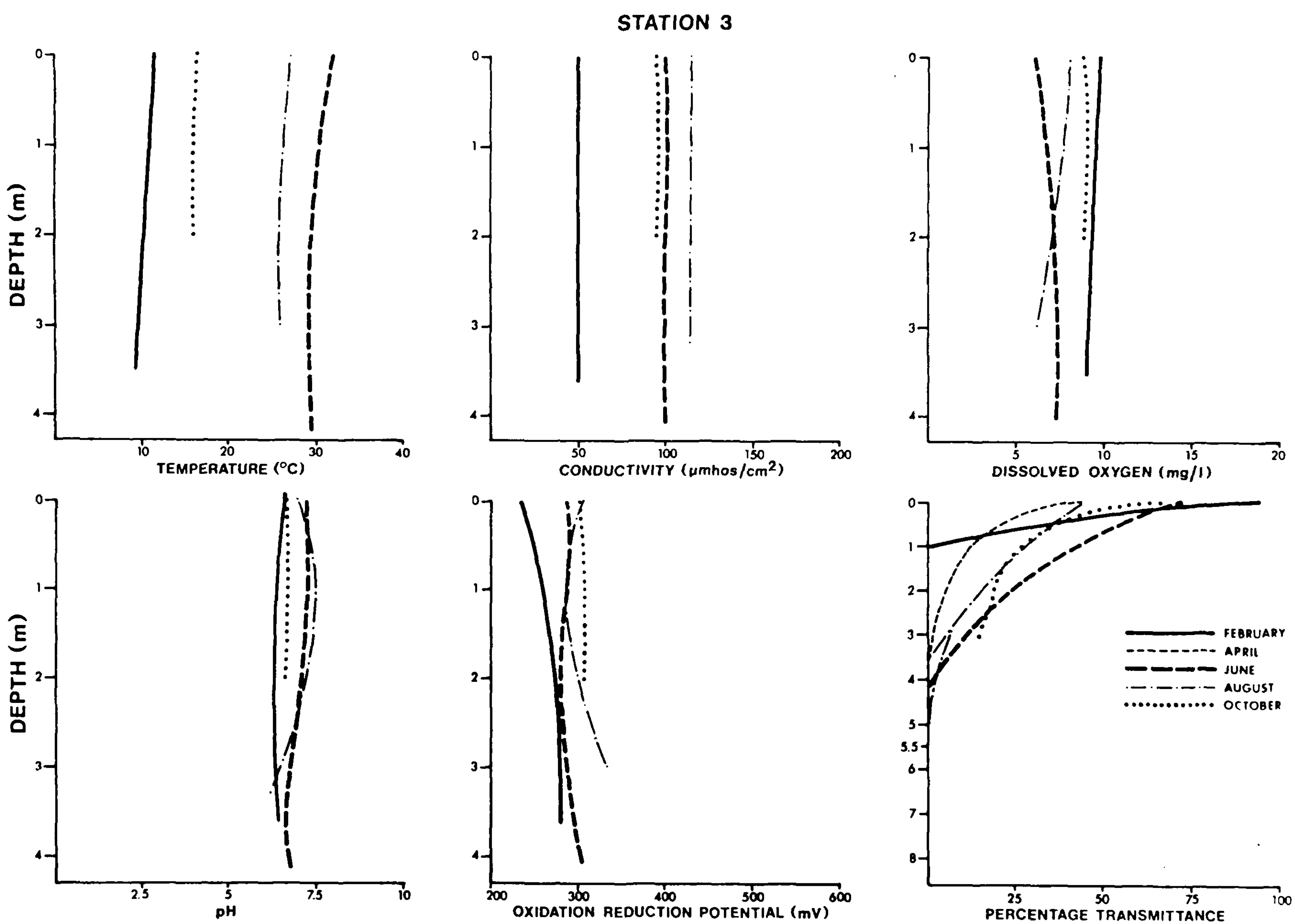


Figure B-3. Summary of in situ measurements by depth and month, Station 3, Clarks Hill Lake, February-October 1981.

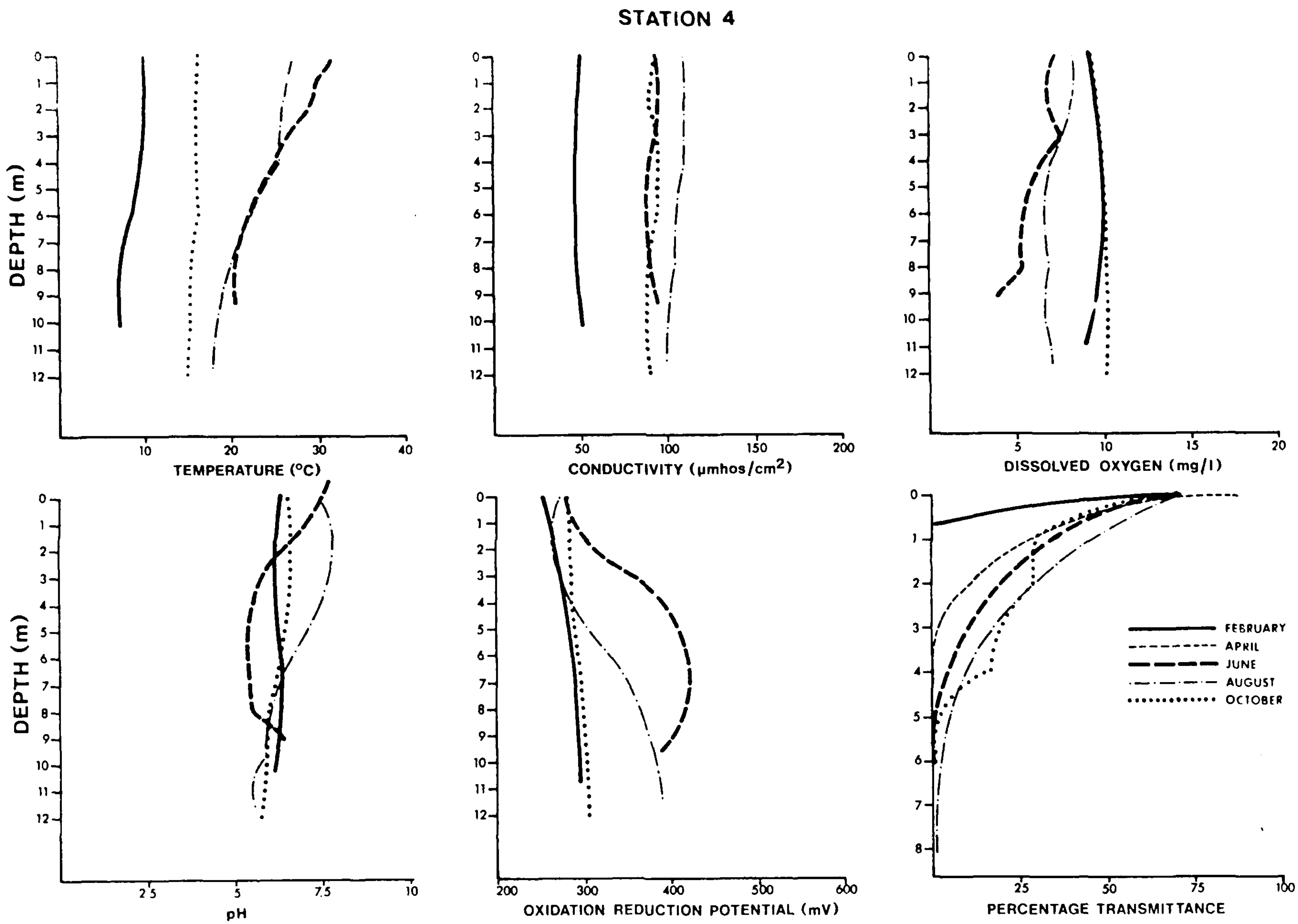


Figure B-4. Summary of in situ measurements by depth and month, Station 4, Clarks Hill Lake, February-October 1981.

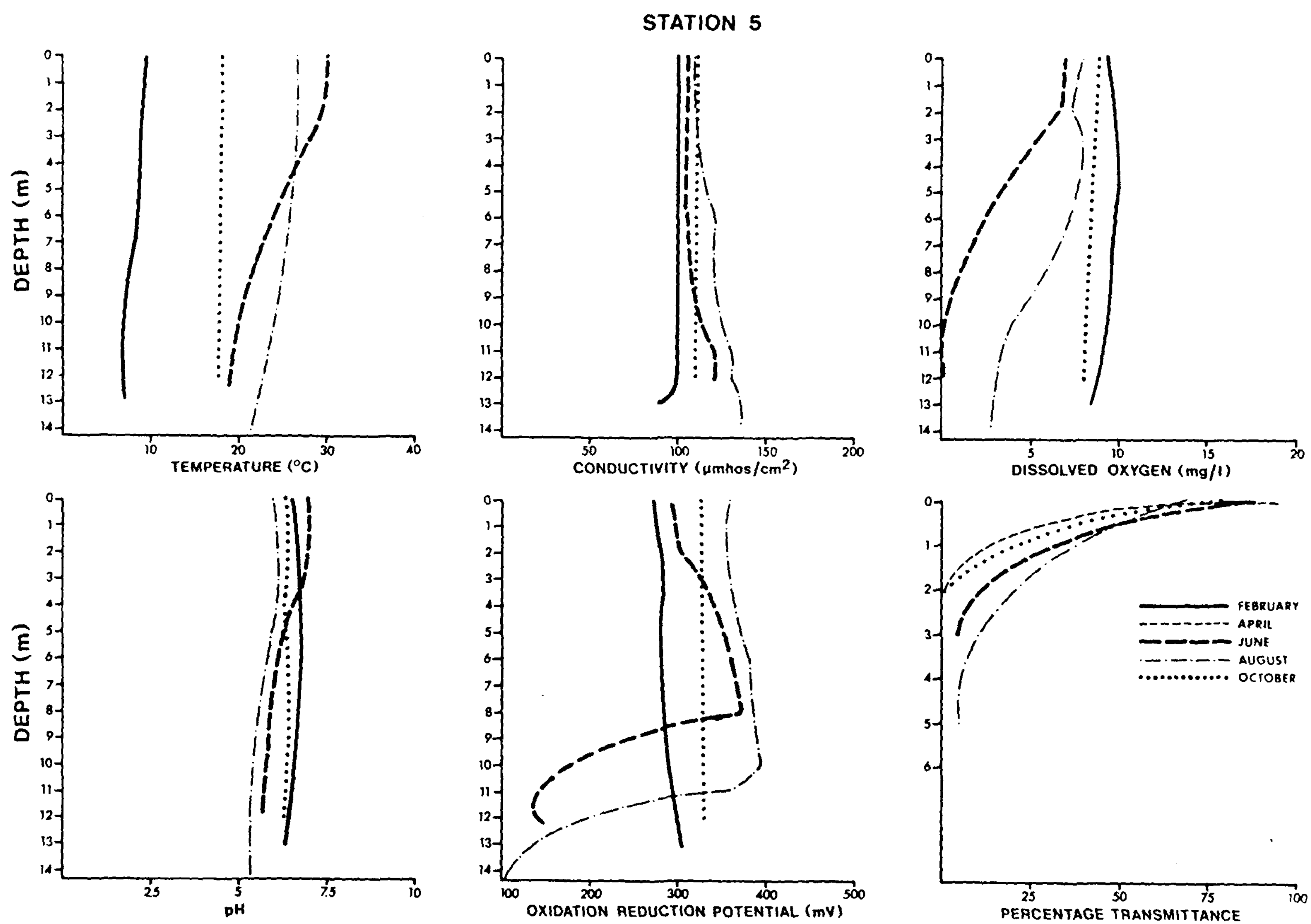


Figure B-5. Summary of *in situ* measurements by depth and month, Station 5, Clarks Hill Lake, February-October 1981.

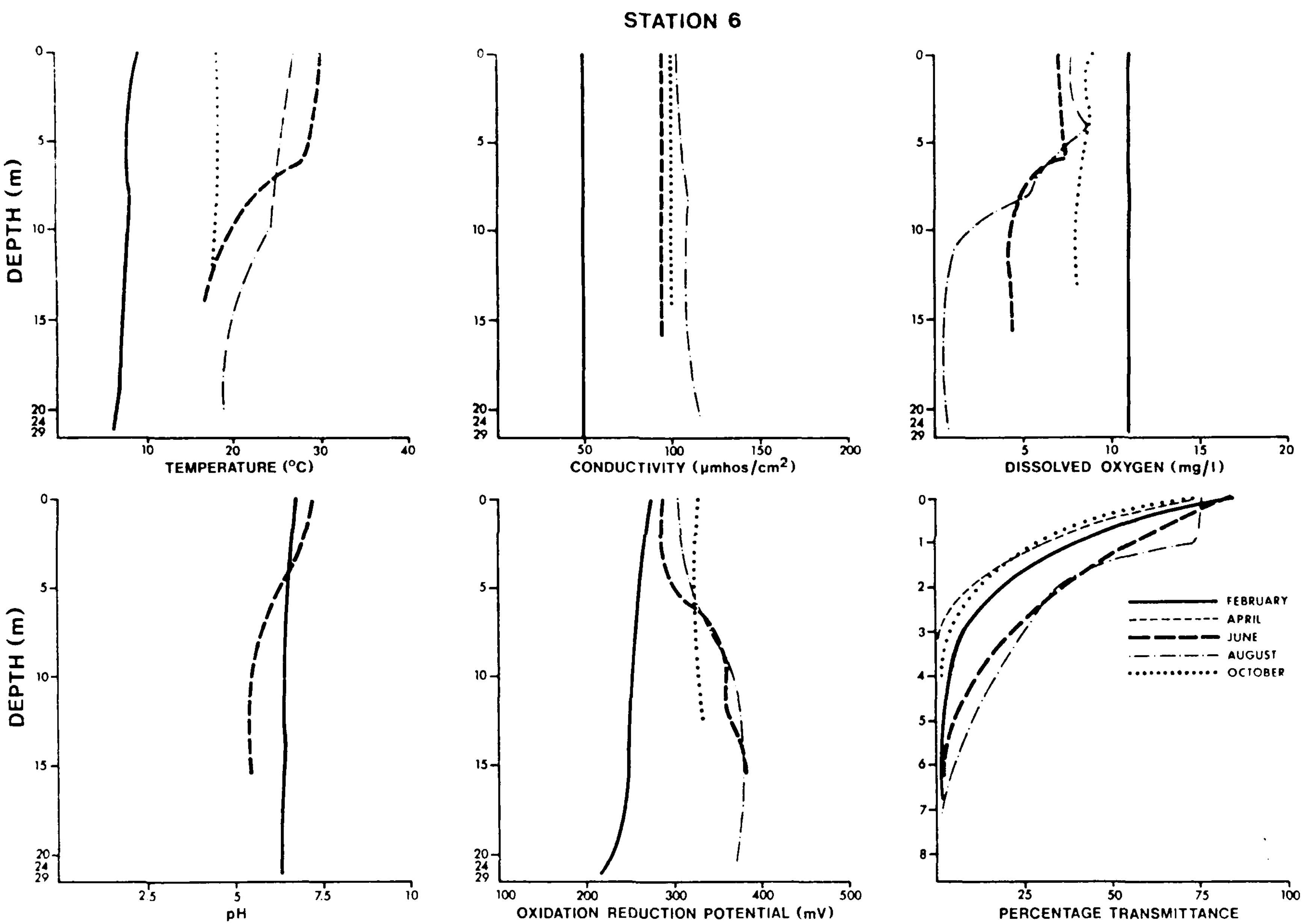


Figure B-6. Summary of in situ measurements by depth and month, Station 6, Clarks Hill Lake, February-October 1981.

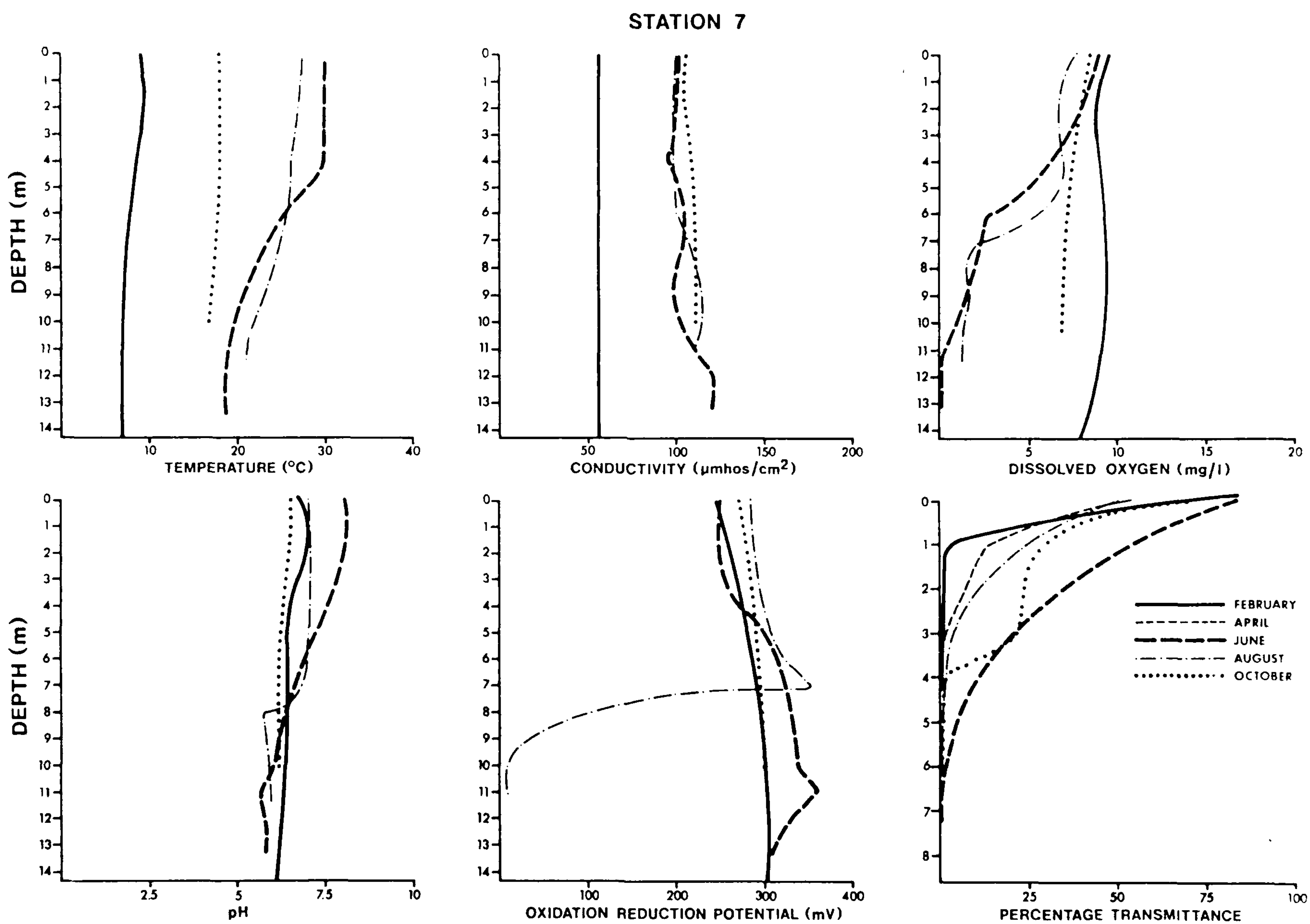


Figure B-7. Summary of in situ measurements by depth and month, Station 7, Clarks Hill Lake, February-October 1981.

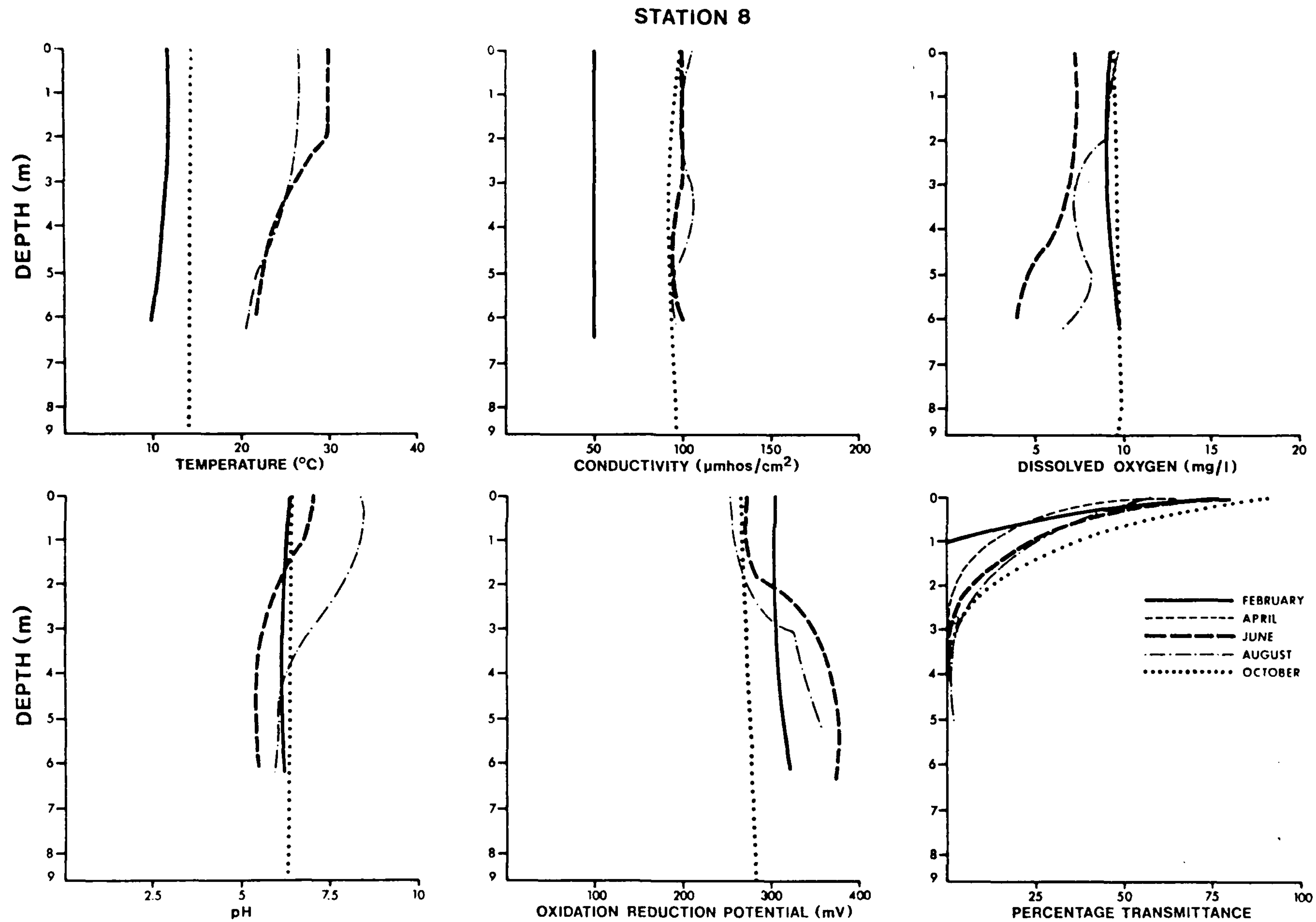


Figure B-8. Summary of in situ measurements by depth and month, Station 8, Clarks Hill Lake, February-October 1981.

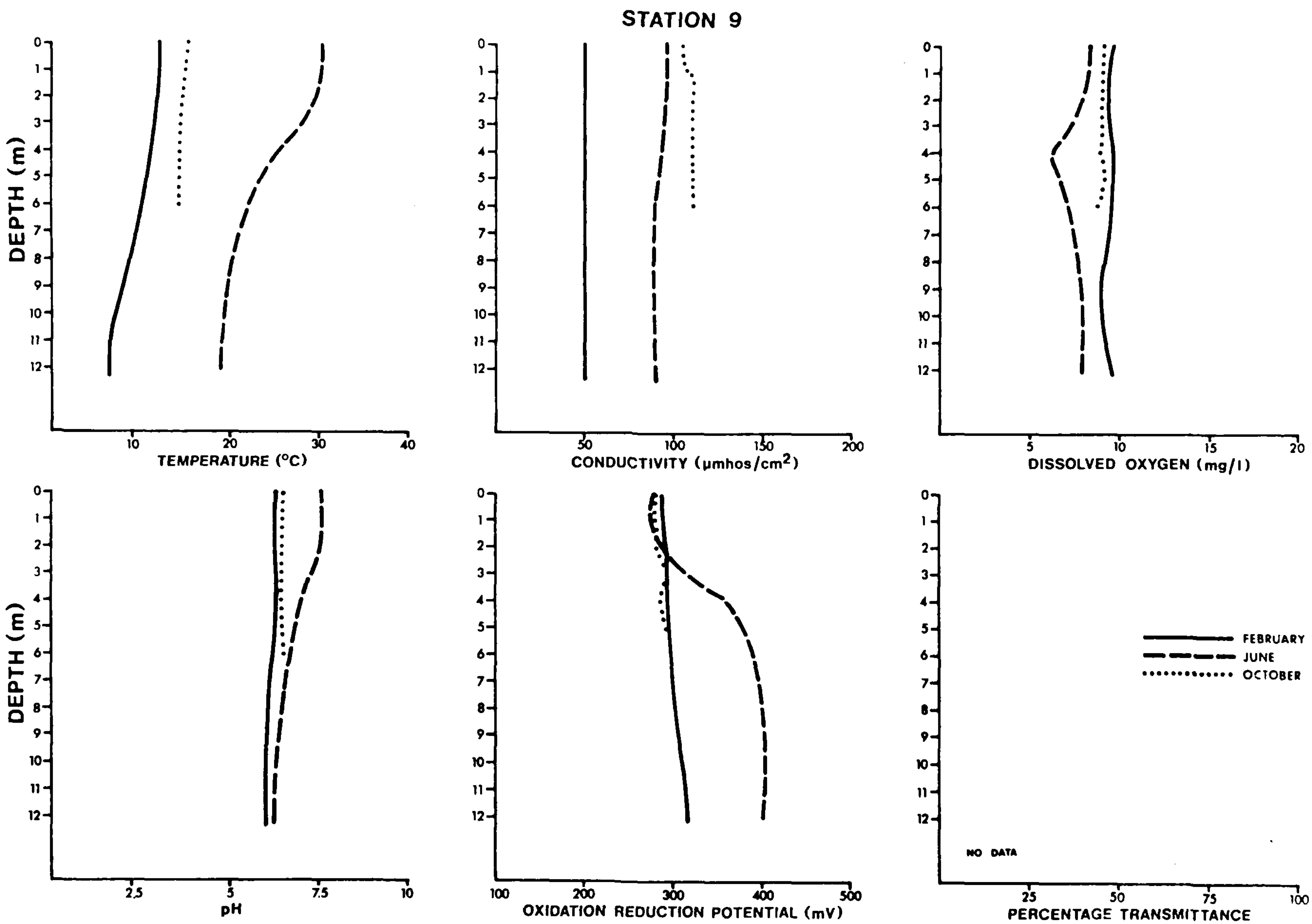


Figure B-9. Summary of in situ measurements by depth and month, Station 9, Clarks Hill Lake, February-October 1981.

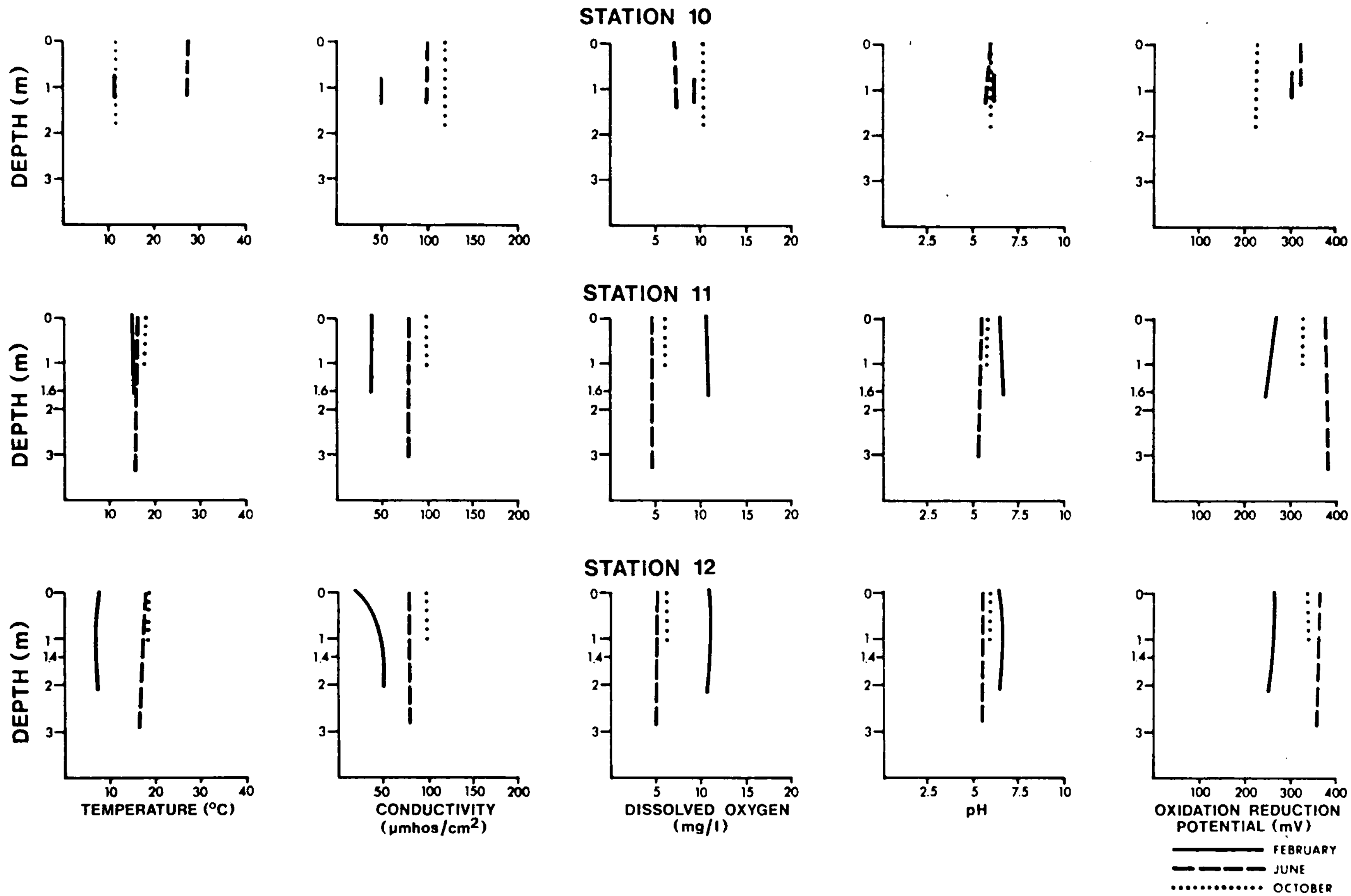


Figure B-10. Summary of in situ measurements by depth and month, Stations 10, 11, and 12, Clarks Hill Lake, February-October 1981.

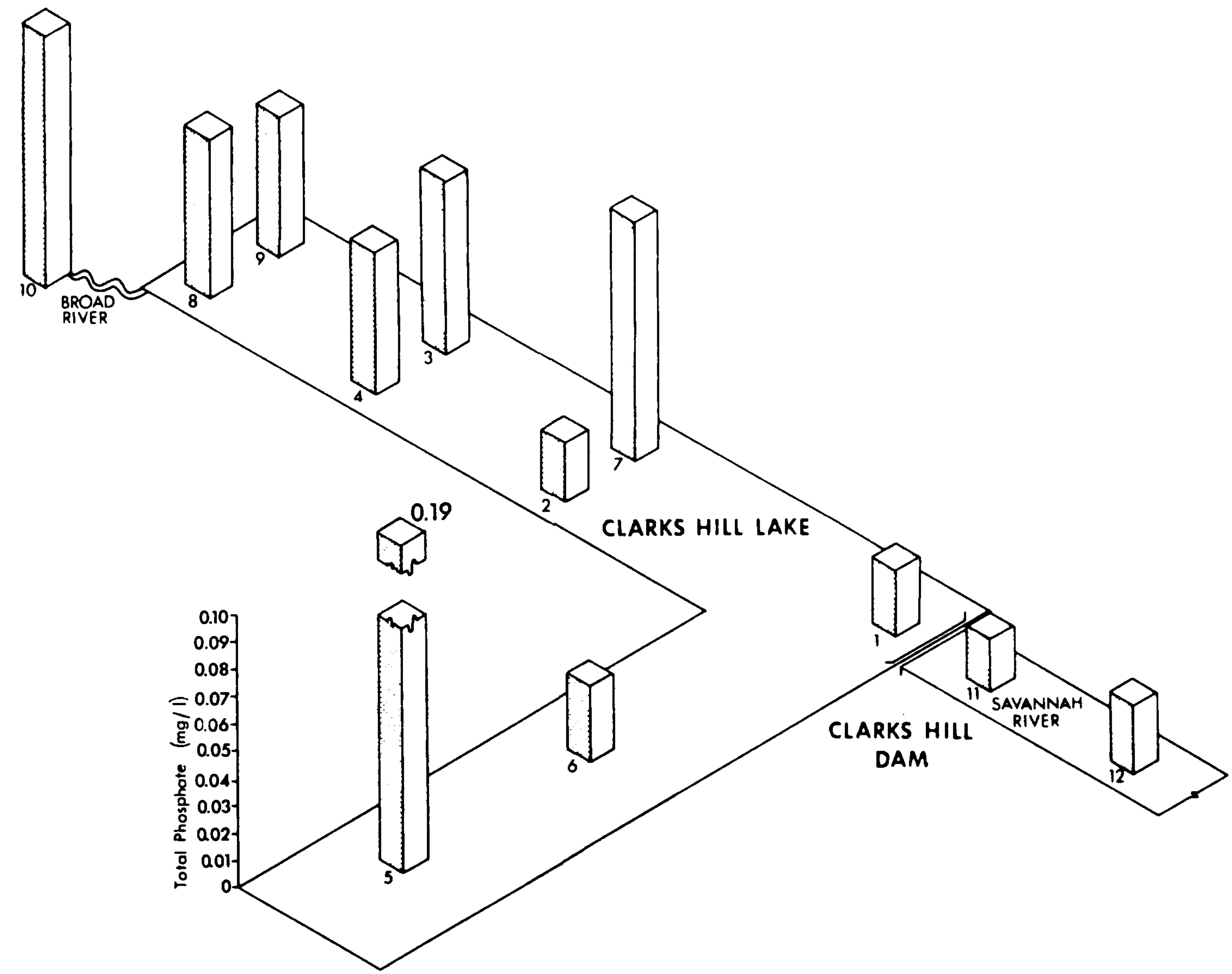


Figure B-11. Mean values of total phosphate (mg/liter), Stations 1 through 12, Clarks Hill Lake, 1981.

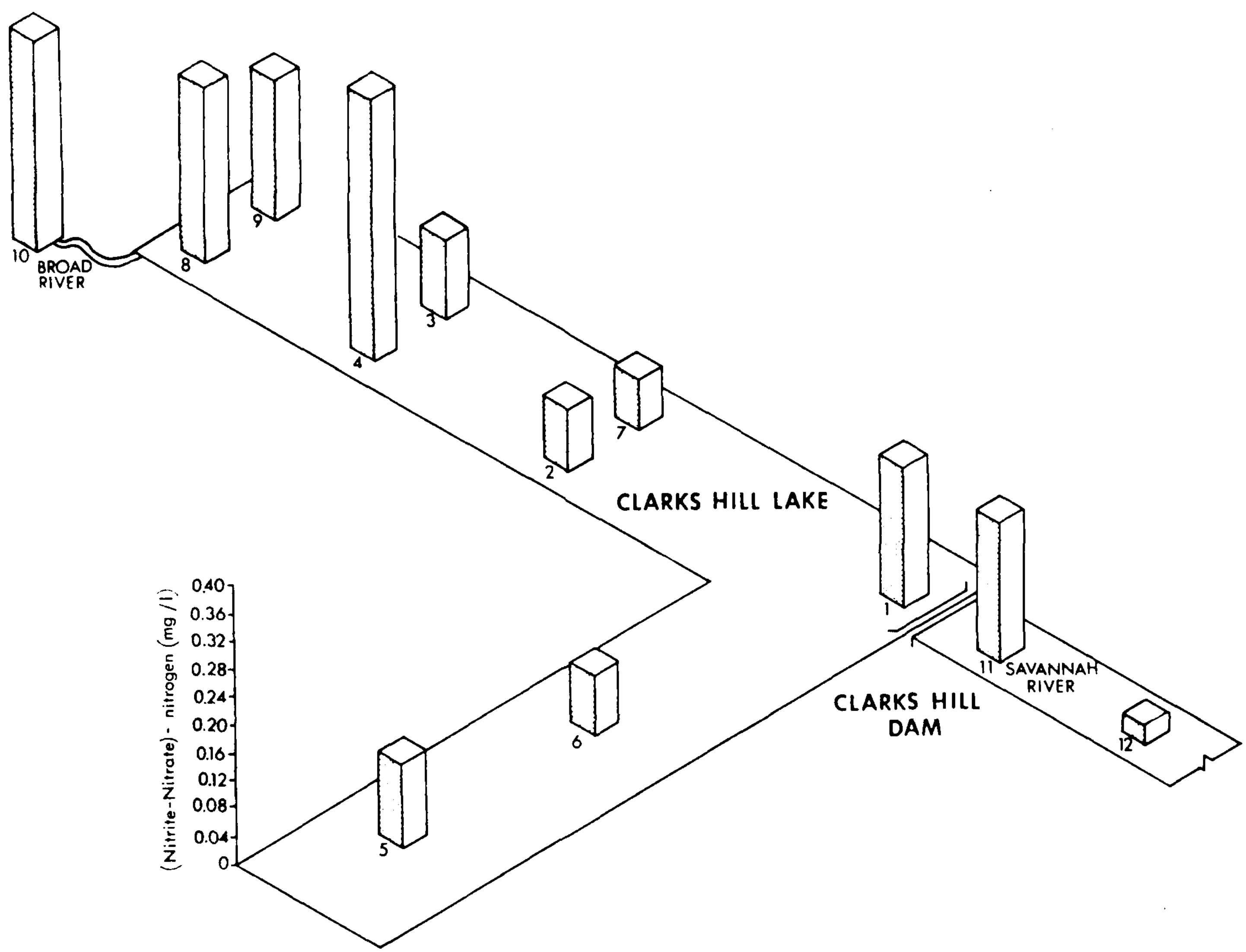


Figure B-12. Mean values of nitrite-nitrate nitrogen (mg/liter), Stations 1 through 12, Clarks Hill Lake, 1981.

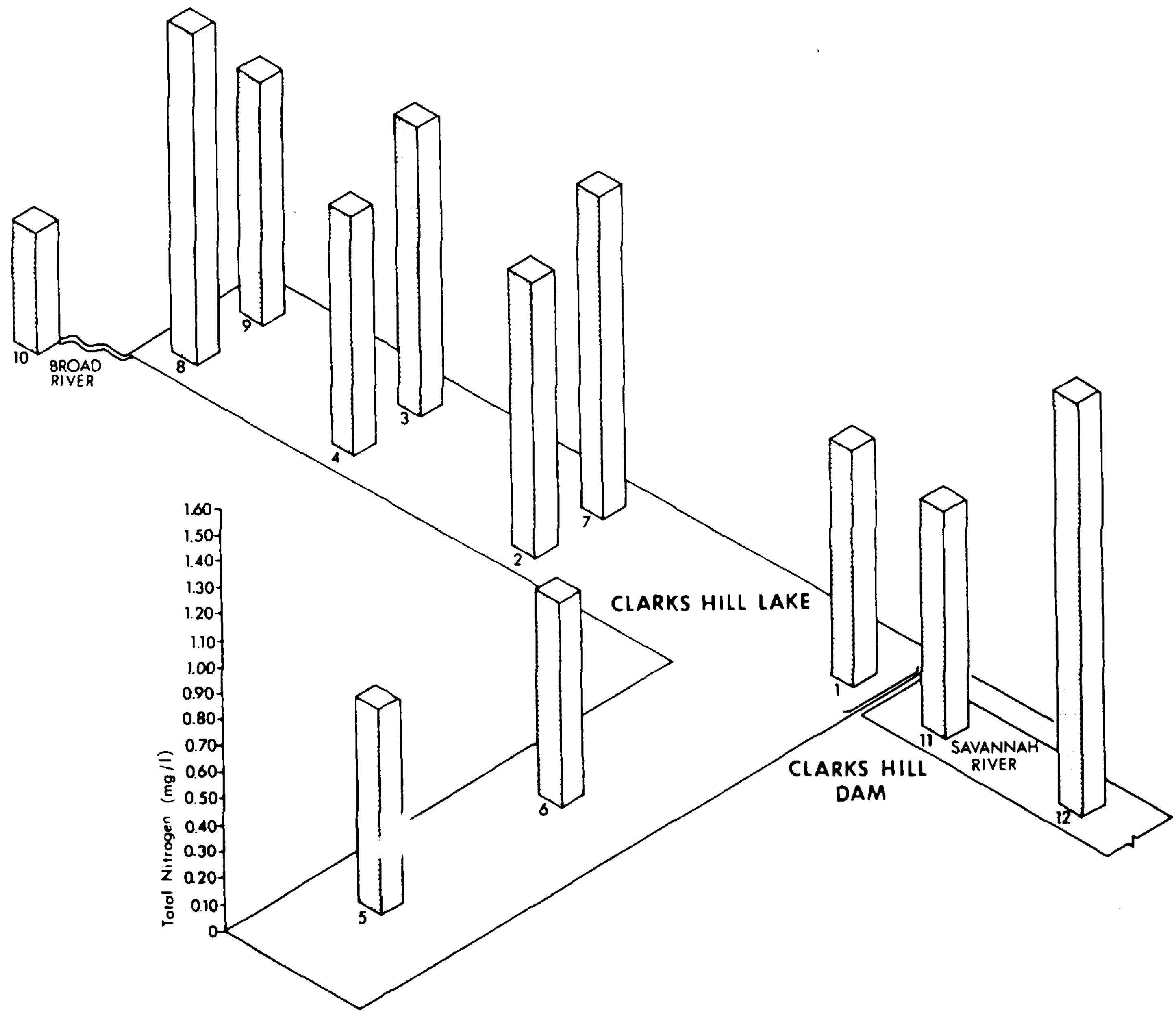


Figure B-13. Mean values of total nitrogen (mg/liter), Stations 1 through 12, Clarks Hill Lake, 1981.

TABLE B-1

TISSUE, SEDIMENT AND WATER PARAMETERS AND PROCEDURES
CLARKS HILL LAKE
1981

Storet code number	Parameter	Holding time	Container	Technique	Analytical methodology	Detection limit	Units
	TISSUE ANALYSES						
	Pesticides	6 mo.					
39387	Dieldrin		non-porous	refrigerate	Pesticide Analytical		
39349	Chlordane		polyethyl	on dry ice	Manual, Vol. I.		
39414	Hepatochlor		Teflon		Methods which detect	1.0	µg/kg
39784	Lindane				multiple residue. U.S.		
39407	Toxaphene				Dept. of Health and		
39317	DDD				Human Services for		
39322	DDE				FDA.		
39317	DDT				USEPA interim methods		
39755	Mirex				for the sampling and		
39520	PCB				analysis of priority pollutants in sediments and fish tissue. EPA Support Lab. Cincinnati, Ohio		
01002	arsenic, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 206.2	1.0	mg/kg
01027	cadmium, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 213.2	0.1	mg/kg
00927	chromium, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 218.2	1.0	mg/kg
01051	lead, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 239.2	1.0	mg/kg
71900	mercury, total	38 days glass 13 days plastic	plastic or glass	HNO_3 to pH<2	EPA method 245.1	0.1	mg/kg
01147	selenium, total	38 days glass 13 days plastic	plastic or glass	HNO_3 to pH<2	EPA method 270.2	2	mg/kg
01092	zinc, total	38 days glass 13 days plastic	plastic or glass	HNO_3 to pH<2	EPA method 289.1	0.05	mg/kg
	SEDIMENT ANALYSES						
00505	volatile solids	7 days	plastic or glass	cool, 4°C	EPA 160.4	-	mg/kg
00680	TOC	28 days	plastic or glass	cool, 4°C	EPA 415.1	1.0	mg/g
00627	TKN	28 days	plastic or glass	refrigerate	EPA 351.3	1.0	mg/kg
00557	oil and grease	28 days	glass	refrigerate	Std. methods 503D	-	mg/kg
00668	phosphate, total	48 hrs	glass	regrigerate	424C std. method	0.01	mg/kg
01042	copper, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 220.1	0.02	mg/kg
01045	iron, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 236.1	0.03	mg/kg
01051	lead, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 239.1	0.1	mg/kg
01027	cadmium, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 213.1	0.005	mg/kg
01067	nickel, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 249.1	0.04	mg/kg
01092	zinc, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 289.1	0.005	mg/kg

TABLE B-1
(continued)
TISSUE, SEDIMENT AND WATER PARAMETERS AND PROCEDURES
CLARKS HILL LAKE
1981

Storet code number	Parameter	Holding time	Container	Technique	Analytical methodology	Detection limit	Units
			SEDIMENT ANALYSES (cont'd)				
01002	arsenic, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 206.2	1.0	mg/kg
01034	chromium, total	6 mo.	plastic or glass	HNO_3 to pH<2	EPA method 218.1	0.05	mg/kg
01055	manganese, total	6 mo.	plastic or glass	HNO_3 to	EPA method 263.1	0.01	mg/kg
71900	mercury, total	38 days glass 13 days plastic	plastic or glass	HNO_3 to pH<2	EPA method 245.1	0.1	mg/kg
	Pesticides:[a]	24 hrs. (extraction)	glass Teflon-lined caps	cool, 4°C	Pesticide Analytical Manual, Vol. I Methods which detect multiple residue. U.S. Dept. of Health and Human Services for FDA USEPA interim methods for the sampling and analysis of priority pollutants in sediments and fish tissue. EPA Support Lab. Cincinnati, Oh	1.0	µg/kg
39783	Lindane						
39413	Hepatochlor						
39333	Aldrin						
39393	Endrin						
39311	DDD						
39321	DDE						
39301	DDT						
39758	Mirex						
39351	Chlorodane						
39403	Toxaphene						
39383	Dieldrin						
39519	PCB						
			WATER ANALYSES				
00530	residue tot. nonfilter.	7-14 days	plastic or glass	refrigerate	EPA method 160.1	1.0	mg/l
70300	residue tot. filt.	7-14 days	plastic or glass	refrigerate	EPA method 160.2	1.0	mg/l
00076	turbidity	7 days	plastic or glass	cool, 4°C	EPA method 180.1	0.05	NTU
00630	(NO_2+NO_3)-N	28 days	plastic or glass	cool, 4°C H_2SO_4 to pH<2	EPA method 353.2	0.001	mg/l
00610	NH_3-N	28 days	plastic or glass	cool, 4°C H_2SO_4 to pH<2	EPA method 350.1	0.01	mg/l
00665	phosphate, tot.	48 hrs	plastic or glass	cool, 4°C H_2SO_4 to pH<2	EPA method 365.2	0.01	mg/l
00671	orthophosphate	24 hrs	plastic or glass	filter on site, cool 4°C	EPA method 365.2	0.01	mg/l
00410	alkalinity (pH 4.5)	14 days	plastic or glass	refrigerate	EPA method 310.1	1.0	mg $CaCO_3$/l
-	free CO_2 (calc)	-	-	-	Std. method 406 C	-	mg/l
00081	color	48 hrs	plastic or glass	refrigerate	EPA method 110.2	5	pt-co units
00625	TKN	28 days	plastic or glass	refrigerate add H_2SO_4 to pH<2	EPA method 351.3	1.0	mg/l

TABLE B-1
(continued)
TISSUE, SEDIMENT AND WATER PARAMETERS AND PROCEDURES
CLARKS HILL LAKE
1981

Storet code number	Parameter	Holding time	Container	Technique	Analytical methodology	Detection limit	Units
			WATER ANALYSES (cont'd)				
00680	TOC	28 days	plastic or glass	cool, 4°C H_2SO_4 or HCl to pH<2	EPA method 415.1	1.0	mg/l
00745	sulfide diss	28 days	plastic or glass	refrigerate: add 4 drops zinc-acetate/100ml	EPA method 376.2	0.05	mg/l
-	(-) unionized H2S (calc)	-	-	-	std. methods 427 E		
00945	sulfate, total	28 days	plastic or glass	refrigerate	EPA method 375.4	1.0	$mgSO_4$
	hardness (calc)	-	-	-	std methods 314 A p. 195	-	mg equiv $CaCO_3$/l
	chloride	7 days	plastic or glass	none req.	std. methods 407 A p. 270	1.0	mg/l
00310	BOD_5	48 hrs	plastic or glass	refrigerate	EPA method 405.1	2.0	mg/l
00340	COD	28 days	plastic or glass	H_2SI_4 to pH<2	EPA method 410.4	5.0	mgCO/l
01045	iron, total	6 mos	plastic or glass	NHO_3 to pH<2	EPA method 236.1	0.03	mg/l
	iron II	-	glass	2 ml HCl/ 100 ml	Std. method 315.B p. 201	0.02	mg/l
01055	manganese,tot.	6 mos	plastic or glass	HNO_3 to pH<2	EPA method 243.1	0.01	mg/l
01056	manganese, diss	6 mos	plastic or glass	HNO_3 to pH<2	EPA method 243.1	0.01	mg/l
00916	calcium, total	6 mos	plastic or glass	HNO_3 to pH<2	EPA method 215.1	0.001	mg/l
00927	magnesium, tot.	6 mos	plastic or glass	HNO_3 to pH<2	EPA method 242.1	0.002	mg/l
00929	sodium, total	6 mos	plastic or glass	HNO_3 to pH<2	EPA method 273.1	0.01	mg/l
00937	potassium, tot	6 mos	plastic or glass	HNO_3 to pH<2	EPA method 258.1	0.10	mg/l

[a]1. Pesticide Analytical Manual, Volume I, "Methods which detect multiple residues". U.S. Department of Health and Human Services. Food and Drug Administration.

2. U.S. Environmental Protection agency interim methods for the sampling and analysis of priority pollutants in sediments and fish tissue. Environmental monitoring and support laboratory, Cincinnati, Ohio 45268.

REFERENCE: EPA: methods for chemical analysis of water and wastes EPA-60014-79-020, March 1979.

Std. Methods: Standard methods for the examination of water and wastewater, 15th edition, 1980. APHA-AWWA-WPCF.

CH8
TABLEB-3B

TABLE B-2

MEANS, STANDARD DEVIATIONS AND RANGES OF SELECTED CHEMICAL PARAMETERS (mg/l)
STATIONS 1 THROUGH 12
CLARKS HILL LAKE
1981

Parameter	Station	N	Mean	Standard deviation	Range	
					Minimum value	Maximum value
Alkalinity	1	4	14.312	4.5706	10.2	20.0
	2	4	13.000	2.0000	12.0	16.0
	3	4	12.625	2.4958	10.5	16.0
	4	4	11.875	3.4731	7.5	16.0
	5	4	14.416	3.8837	10.5	18.0
	6	4	12.937	1.8750	11.0	15.0
	7	4	15.833	1.6832	14.5	18.0
	8	4	11.750	5.2041	4.5	16.0
	9	4	10.375	2.8686	7.0	14.0
	10	4	18.375	2.4958	16.5	22.0
	11	4	11.875	1.1814	11.0	13.5
	12	4	13.500	2.6457	11.0	17.0
Biochemical oxygen demand (BOD)	1	3	2.000	0.0000	2	2.0
	2	3	2.000	0.0000	2	2.0
	3	3	3.833	3.1754	2	7.5
	4	3	2.833	1.4433	2	4.5
	5	3	2.500	0.8660	2	3.5
	6	3	2.000	0.0000	2	2.0
	7	3	2.500	0.5000	2	3.0
	8	3	3.833	1.7559	2	5.5
	9	3	4.000	1.8027	2	5.5
	10	3	4.000	2.0000	2	6.0
	11	3	2.833	1.0408	2	4.0
	12	3	2.833	1.0408	2	4.0
Chloride	1	2	1.750	1.0606	1	2.5
	2	2	1.750	1.0606	1	2.5
	3	2	1.500	0.7071	1	2.0
	4	2	1.250	0.3535	1	1.5
	5	2	3.625	0.8838	3	4.2
	6	2	2.000	0.0000	2	2.0
	7	2	1.500	0.7071	1	2.0
	8	2	1.500	0.7071	1	2.0
	9	2	1.250	0.3535	1	1.5
	10	2	1.750	1.0606	1	2.5
	11	2	2.000	1.4142	1	3.0
	12	2	1.500	0.7071	1	2.0
Chemical oxygen demand (COD)	1	3	15.166	12.7704	5	29.5
	2	3	19.666	13.0416	10	34.5
	3	3	9.333	5.8595	5	16.0
	4	3	19.166	13.5493	5	32.0
	5	3	14.666	15.8850	5	33.0
	6	3	13.333	9.3853	5	23.5
	7	3	13.666	7.3711	8	22.0
	8	3	9.666	7.2342	5	18.0
	9	3	13.000	6.5574	6	19.0
	10	3	15.333	14.1804	5	31.5
	11	3	12.000	11.2694	5	25.0
	12	3	12.666	10.7858	5	25.0
Color	1	3	11.666	2.8868	10	15
	2	3	21.666	11.5470	15	35
	3	3	40.000	27.8388	15	70
	4	3	36.666	28.8675	20	70
	5	3	41.666	25.6580	20	70
	6	3	18.333	2.8868	15	20
	7	3	36.666	28.8675	20	70
	8	3	36.666	28.8675	20	70
	9	3	36.666	28.8675	20	70
	10	3	45.000	15.0000	30	60
	11	3	15.000	5.0000	10	20
	12	3	16.666	5.7735	10	20

CH7
TABLE1

TABLE B-2
(continued)
MEANS, STANDARD DEVIATIONS AND RANGES OF SELECTED CHEMICAL PARAMETERS (mg/l)
STATIONS 1 THROUGH 12
CLARKS HILL LAKE
1981

					Range	
Parameter	Station	N	Mean	Standard deviation	Minimum value	Maximum value
Free carbon dioxide (CO_2)	1	4	3.962	2.9921	0.10	7.200
	2	4	2.517	2.0795	0.10	5.070
	3	4	0.970	0.9068	0.10	2.200
	4	4	2.822	3.2187	0.10	7.440
	5	4	2.760	2.3416	0.10	5.700
	6	4	2.107	1.7771	0.10	4.430
	7	4	2.258	1.5341	0.10	3.600
	8	4	0.950	0.6030	0.10	1.435
	9	4	1.412	0.9488	0.10	2.220
	10	4	1.992	1.4062	0.10	3.300
	11	4	4.530	3.4615	0.10	7.590
	12	4	4.792	3.8259	0.10	8.830
Hardness	1	2	10.550	0.4242	10.25	10.85
	2	2	10.725	1.9445	9.35	12.10
	3	2	8.000	1.2727	7.10	8.90
	4	2	9.350	0.5656	8.95	9.75
	5	2	12.200	1.6970	11.00	13.40
	6	2	11.125	1.6617	9.95	12.30
	7	2	13.225	0.3182	13.00	13.45
	8	2	9.825	3.1466	7.60	12.05
	9	2	10.225	3.8537	7.50	12.95
	10	2	11.725	1.8738	10.40	13.05
	11	2	10.050	1.2020	9.20	10.90
	12	2	10.425	1.8031	9.15	11.70
Nitrogen ammonia	1	4	0.058	0.0893	<0.010	0.192
	2	4	0.047	0.0325	0.012	0.091
	3	4	0.055	0.0531	<0.010	0.111
	4	4	0.073	0.0665	0.017	0.166
	5	4	0.087	0.0808	0.033	0.208
	6	4	0.097	0.1483	<0.010	0.319
	7	4	0.098	0.0694	0.030	0.192
	8	4	0.104	0.1523	0.015	0.332
	9	4	0.031	0.0167	<0.010	0.050
	10	4	0.036	0.0254	0.010	0.060
	11	4	0.021	0.0108	0.005	0.030
	12	4	0.179	0.3328	<0.010	0.679
Nitrate-nitrite	1	4	0.195	0.2091	0.053	0.504
	2	4	0.086	0.0694	0.044	0.190
	3	4	0.111	0.1419	0.001	0.313
	4	4	0.369	0.4734	0.041	1.051
	5	4	0.117	0.1091	0.022	0.254
	6	4	0.086	0.0447	0.055	0.152
	7	4	0.072	0.0814	0.004	0.186
	8	4	0.250	0.2116	0.065	0.527
	9	4	0.201	0.1064	0.138	0.360
	10	4	0.296	0.2177	0.126	0.605
	11	4	0.197	0.0486	0.139	0.258
	12	4	0.226	0.1509	0.124	0.449
TKN, total	1	3	0.900	0.5517	0.325	1.425
	2	3	1.041	1.1347	0.325	2.350
	3	3	1.091	1.2557	0.240	2.533
	4	3	0.913	1.2659	0.165	2.375
	5	3	0.767	0.7049	0.235	1.566
	6	3	0.771	0.8553	0.165	1.750
	7	3	1.210	1.3527	0.315	2.766
	8	3	1.258	1.2083	0.200	2.575
	9	3	0.923	0.9568	0.170	2.000
	10	3	0.445	0.3606	0.190	0.700
	11	3	0.848	0.6584	0.145	1.450
	12	3	1.540	1.5239	0.120	3.150

TABLE B-2
(continued)
MEANS, STANDARD DEVIATIONS AND RANGES OF SELECTED CHEMICAL PARAMETERS (mg/l)
STATIONS 1 THROUGH 12
CLARKS HILL LAKE
1981

Parameter	Station	N	Mean	Standard deviation	Range	
					Minimum value	Maximum value
Sulfate, total	1	2	2.00	1.4142	1.0	3.0
	2	2	4.25	1.7678	3.0	5.5
	3	2	8.75	6.7175	4.0	13.5
	4	2	9.75	9.5459	3.0	16.5
	5	2	14.25	11.6673	6.0	22.5
	6	2	3.75	1.7678	2.5	5.0
	7	2	14.50	13.4350	5.0	24.0
	8	2	13.25	2.4749	11.5	15.0
	9	2	17.50	3.5355	15.0	20.0
	10	2	7.75	2.4749	6.0	9.5
	11	2	3.00	1.4142	2.0	4.0
	12	2	2.75	0.3536	2.5	3.0
Total organic cargon (TOC)	1	4	3.01	1.4608	2.20	5.20
	2	4	3.50	1.3291	2.40	5.30
	3	4	4.12	1.5663	3.16	6.45
	4	4	3.58	2.3341	1.30	6.80
	5	4	4.43	2.4162	3.05	8.05
	6	4	3.21	1.7208	1.00	5.20
	7	4	4.29	2.8686	2.30	8.55
	8	4	4.67	2.6537	2.05	8.35
	9	4	3.27	2.2039	1.30	6.40
	10	4	3.97	2.0035	1.35	5.90
	11	4	3.17	1.4192	1.90	5.10
	12	4	3.05	0.8897	2.15	4.00
Turbidity	1	3	4.73	1.1730	3.80	6.05
	2	3	9.36	7.0948	4.45	17.50
	3	3	22.15	23.5009	4.20	48.75
	4	3	20.33	24.8333	5.40	49.00
	5	3	29.91	33.0741	5.25	67.50
	6	3	5.66	2.1286	4.15	8.10
	7	3	33.43	47.2599	5.55	88.00
	8	3	22.75	27.5087	6.05	54.50
	9	3	20.20	23.6425	6.55	47.50
	10	3	21.01	18.6400	5.05	41.50
	11	3	8.85	7.3029	2.90	17.00
	12	3	5.46	2.2138	3.70	7.95
Un-ionized hydrogen sulfide	1	2	<0.05	0	<0.05	<0.05
	2	2	<0.05	0	<0.05	<0.05
	3	2	<0.05	0	<0.05	<0.05
	4	2	<0.05	0	<0.05	<0.05
	5	2	<0.05	0	<0.05	<0.05
	6	2	<0.05	0	<0.05	<0.05
	7	2	<0.05	0	<0.05	<0.05
	8	2	<0.05	0	<0.05	<0.05
	9	2	<0.05	0	<0.05	<0.05
	10	2	<0.05	0	<0.05	<0.05
	11	2	<0.05	0	<0.05	<0.05
	12	2	<0.05	0	<0.05	<0.05

CH 7
TABLE1

TABLE B-3

COMPARISON OF PHYSICOCHEMICAL PARAMETERS
CLARKS HILL LAKE
1973 AND 1981

	1973[a]		1981[b]	
Parameter	Range	Mean	Range	Mean
Temperature (°C)	11.2-31.3	-	6.3-32.0	-
Dissolved oxygen (mg/l)	0.0-11.2	-	0.17-11.35	-
Conductivity (μmhos)	30.0-116.0	-	40.0-170.0	-
pH	5.6-8.3	6.9[c]	4.38-9.54	5.79[c]
Total alkalinity (mg/l)	10.0-38.0	13.7	<1-24.0	13.0
Total phosphate (mg/l)	0.006-0.097	0.027	<0.01-1.00	0.065
Orthophosphate (mg/l)	0.002-0.052	0.012	<0.01-0.02	0.011
Nitrate - nitrite (mg/l)	0.020-0.340	0.253	<0.001-0.809	0.166
Ammonia (mg/l)	0.020-1.290	0.248	<0.010-0.679	0.073
Total Kjeldahl nitrogen (mg/l)	0.200-2.300	0.887	<0.01-3.70	0.99

[a]Based on 11 stations and three sampling periods.

[b]Based on 12 stations and four sampling periods.

[c]Means based on transformed data.

CHIIII
TBL-3

TABLE B-4

COMPARISON OF TOTAL PHOSPHATE AND TOTAL NITROGEN CONCENTRATIONS
CLARKS HILL LAKE
1973[a] AND 1981

Parameter	Station 1982	Station (1973)	Concentration (mg/l) 1973	Concentration (mg/l) 1981	Percentage change
Total phosphate (mg/l)	1	(1)	0.021	0.024	+14.3
	2	(6)	0.022	0.022	0.0
	3	(5)	0.025	0.063	+152.0
	4	(4)	0.021	0.052	+147.6
	5	(3)	0.030	0.195	+550.0
	6	(2)	0.022	0.028	+27.3
	7	(7)	0.041	0.087	+112.2
	8	(10)	0.043	0.059	+37.2
	9	(9)	0.024	0.051	+112.5
	10	(G1)	0.089	0.092	+3.4
	11	(E2)	0.021	0.019	-9.5
	12		-[b]	0.025	-
Total nitrogen (mg/l)	1	(1)	0.451	0.900	+99.6
	2	(6)	0.365	1.042	+185.5
	3	(5)	0.649	1.091	+68.1
	4	(4)	0.352	0.913	+159.4
	5	(3)	0.532	0.767	+44.2
	6	(2)	0.397	0.772	+94.4
	7	(7)	0.557	1.211	+117.4
	8	(10)	0.555	1.258	+126.7
	9	(9)	0.437	0.923	+111.2
	10	(G1)	0.618	0.445	-28.0
	11	(E2)	0.683	0.848	+24.2
	12		-[b]	1.540	-

[a] EPA (1976b).

[b] Sampling was not conducted at this station during 1973-1974.

CHIII
TBL-4

C. BACTERIA

INTRODUCTION

The bacteria Escherichia coli and related organisms are designated as fecal coliforms. They are normal inhabitants of the large intestine of man and other warm-blooded animals and are consequently present in their feces. These bacterial species in water are evidence of fecal contamination of animal origin. The disease-producing potential of the water can be evaluated by quantification of these fecal contaminants.

The objective of this study was to determine water quality in the Clarks Hill Lake and adjacent waters by quantifying coliform populations.

MATERIALS AND METHODS

Samples for fecal coliform determination were collected at 12 stations located in Clarks Hill Lake at various state park beaches and recreational areas during February and August 1981 (Figure A-1). Duplicate whole-water samples were obtained from a depth of 0.3 meter using presterilized polyethylene containers, placed on ice and immediately shipped to the laboratory for analysis. Upon arrival in the laboratory, bacteria samples were inventoried, shaken to achieve homogeneity and then inoculated. The multiple-tube fermentation technique was used to analyze appropriate sample dilutions (APHA, 1976). Lauryl tryptose broth fermentation tubes were inoculated and incubated in a swirling water bath for 48 ± 3 hours at 35 ± 0.5°C. Transfers were made from all tubes that indicated gas production into EC medium fermentation tubes for the fecal coliform determination. EC medium tubes were incubated in a swirling water bath for 24 ± 2 hours at 44.5 ± 0.2°C. Tubes of brilliant green lactose bile broth were inoculated and incubated simultaneously for the Conf'rmed Test. Gas production within 24 hours was recorded as a positive reaction. Fecal coliform counts were computed and reported in terms of the Most Probable Number (MPN). The 95-percent confidence limits for each MPN value were determined.

RESULTS AND DISCUSSION

Fecal coliform counts varied among stations and sampling periods (Appendix Tables C-1 and C-2). The highest mean fecal coliform count (166 per 100 ml of water) was recorded at Station 10 during February and August collections. Overall, Wildwood State Park had the lowest fecal coliform counts, with an average of less than 6 fecal coliforms per 100 ml of water. Quality criteria for bathing water (EPA, 1976) stipulates that, based on a minimum of five samples taken over a 30-day period, the fecal coliform level should not exceed a log mean of 200 per 100 ml and no more than 10 percent of the total samples taken during any 30-day period should exceed 400 per ml. All average values for stations designated for public bathing, recreational purposes or agricultural use were below this recommended limit. All stations meet the National Academy of Science Blue Book (National Technical Advisory Committee, 1968) recommendation of 2000 fecal coliforms per 100 ml for raw surface public water supply sources that are to be given complete treatment (coagulation, filtration and disinfection). No criteria are specified for water supplies receiving minimum treatment (disinfection only).

SUMMARY

All stations tested for fecal coliform levels complied at times of testing for maximum permissible values for public drinking water supplies given complete treatment and for all recreational and agricultural uses.

LITERATURE CITED

APHA (American Public Health Association). 1976. Standard methods for the examination of water and wastewater. 14th ed. Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1976. Quality criteria for water. 79 pp.

National Technical Advisory Committee. 1968. Water quality criteria. U.S. Department of the Interior. Federal Water Pollution Control Administration, Washington, D.C. 234 pp.

D. BENTHIC AND DRIFT MACROINVERTEBRATES

INTRODUCTION

Macroinvertebrates are animals large enough to be seen by the unaided eye and retained by a U.S. Standard No. 30 sieve (28 meshes per inch, 0.595-mm openings; EPA, 1973). They live at least part of their life cycles within or upon suitable substrata in a body of water.

A community of macroinvertebrates in an aquatic system responds to changes in environmental conditions such as temperature, depth, current, substratum, and the concentrations of chemical or organic pollutants. Because macroinvertebrates exhibit limited motility and relatively long life spans, the species composition of a macroinvertebrate community is a function of environmental conditions during the recent past. Thus, these communities are useful indicators of environmental health or perturbation (EPA, 1973).

MATERIALS AND METHODS

Sediment Grain Size Analysis

Sediment samples were collected at Stations 1 through 12 during April and September 1981 (Figure A-1). Sediments used for grain size analysis were collected using an epoxy-coated Ponar grab. One grab was taken at each sampling location and composited into one sample representative of all the sampling locations at each station. Samples were placed in labeled, unbreakable sample containers and shipped on ice to the laboratory.

Three aliquots of approximately 100 g of air-dried sediment were analyzed from each station using a Tyler Ro-Tap sieve shaker equipped with a nest of sieves with meshes of 2.0, 1.0, 0.5, 0.025, 0.0125 and 0.063 mm (Royce, 1970). Each aliquot was shaken for 15 minutes and the mean percentages of the three particle size distributions were calculated. The mean grain diameter and sorting coefficient (standard deviation) were calculated from the station means according to the method of moments outlined in Folk (1961). Complete collection data are found in Appendix Tables D-1 through D-4.

Benthic Macroinvertebrates

Specimens from the benthic community were collected and analyzed in accordance with methods recommended by the EPA (1973), the USGS (1977), and APHA (1980). Benthic samples were taken with a Ponar grab at Stations 1, 3, 5, 7, 9 and 11 in March, July and October 1981 (Figure

A-1). At each lake station (1, 3, 5, 7 and 9), three samples were taken; one each in the littoral (shallow depths), the 1 percent light transmittance level (mid-depths), and well below the 1 percent light transmittance level (deeper portions of the lake). Each sample consisted of a composite of two replicate Ponar grabs (0.1046 m^2 total area per sample). At river Station 11, samples were collected at three equally-spaced intervals across the river and were designated east side, mid-stream, and west side. Again, each sample consisted of two replicate Ponar grabs. Descriptive notes were made regarding the substrate sampled at each station.

Each sample was washed through a U.S. Standard No. 30 mesh sieve to remove fine sediment and detritus. All material retained on the sieve was preserved in a 5-percent formalin solution containing Eosin B and Biebrich Scarlet stains (Williams, 1974). Samples were placed in labeled, unbreakable containers and taken to the laboratory where the macroinvertebrates were hand sorted, preserved in 70-percent ethanol, enumerated and identified to the lowest practicable taxon. Taxonomic references included Frison (1935), Ross (1944), Burks (1953), Needham and Westfall (1955), Brinkhurst (1964, 1965), Brinkhurst and Cook (1966), Mason (1971), Brown (1972), Holsinger (1972), Burch (1972, 1973), Parrish (1975), Beck (1976), Edmunds et al. (1976), Hobbs (1976), Williams (1976), Wiggins (1977), Meritt and Cummins (1978), Oliver et al. (1978), Pennak (1978), Hiltunen and Klemm (1980) and Simpson and Bode (1980). Wet weight biomass, with mollusc shells removed, was determined for whole samples using the blotting technique described by the USGS (1977). The Shannon-Wiener index of diversity (Lloyd et al., 1968) was calculated for each sample. Complete collection data were found in Appendix Tables D-5 through D-22.

Drift Macroinvertebrates

The macroinvertebrate drift community was sampled with multiple-plate artificial substrate samplers (Hester and Dendy, 1962; Fullner, 1971). Each sampler had a surface area of 0.1626 m^2. Samplers were set in the same locations (i.e., surface, mid-depth and deep) from which the benthic samples were taken and were left exposed for the four-week period prior to the benthos collections in March, July and October 1981. When the samplers were retrieved, all colonizing macroinvertebrates were scraped from them. The samples were sieved and preserved in the field, and processed, identified and biomassed in the laboratory as previously described for the benthos samples. Each drift sample consisted of the macroinvertebrates scraped from two replicate artificial substrate samplers (0.3252 m^2 total surface area). Complete collection data are found in Appendix Tables D-23 through D-40.

RESULTS AND DISCUSSION

Sediments

Sediments at the Clarks Hill Lake stations in April 1981 were generally composed of moderately sorted, medium sand. Mean grain sizes ranged from 1.45ϕ at Station 3 to 1.88ϕ at Station 9 (Figure D-1). Descriptions of the sediments from the field notes revealed coarser sediments at the shallow stations and progressively smaller grained sediments at mid-depth and deep stations. The single exception to this generality was Station 6, which was composed of moderately sorted, very fine sand (3.94ϕ mean grain size). Sediment grain size at this station varied only slightly with depth. A possible explanation of the deviation at Station 6 was the relative closeness of the shallow and deep stations when compared to other lake sampling stations. In other words, the depth drop-off was steepest at Station 6. Station 6 was also relatively close to the old main channel of the Georgia Little River where finer sediments would be expected to accumulate.

Sediments at Station 10 in the Broad River were somewhat finer than at the lake sampling stations (mean grain diameter of 2.16 ϕ) and were composed of moderately sorted, fine sand. Sediments from the Savannah River sampling stations were composed of coarse sand at Station 11 (0.05 ϕ mean grain diameter) and medium sand at Station 12 (1.29 ϕ mean grain diameter). The coarser mean grain diameters from the Savannah River stations indicate the higher current velocities of the river, particularly in the Clarks Hill Dam tailwaters (Station 11).

Mean sediment grain diameters at the lake stations were noticeably finer in September than in April and ranged from 3.28ϕ at Station 2 to 5.91ϕ at Station 8 (Figure D-1). All lake stations had poorly sorted, very fine sand or medium silt substrates. Station 9, in an area that will become the tailwaters of the Richard B. Russell Dam, was very similar to the other lake stations. Compared to the large changes in mean grain diameters at most lake stations, Station 6 sediments remained relatively constant. In fact, mean grain diameter at Station 6 was slightly coarser in September than in April. All other lake stations had finer sediments in September.

The steady fall in water level during 1981 rendered the mid-depth and deep stations of April much shallower in September (Figure A-2). This exposed the finer sediments of these formerly deep areas to sampling as shallow and mid-depth stations in September. Combined with the fact that the shallow stations, the major contributors of coarse sediment in April, were dry land in September, the mean grain diameters of nearly all lake stations decreased drastically.

In the Broad River (Station 10), sediment grains were also finer in September as the river's flow rate and water level decreased and allowed the finer sediments to settle out. Sediments in the Savannah River were comparatively unchanged between April and September and indicated an unchanged flow regime during this time.

Despite the interference of the drastic fall in water level, the sediment survey yielded results typically found in North American lakes and reservoirs (Brinkhurst, 1974). Sediments in shallow water were coarser as a result of waves and currents generated by wind and boat traffic, which washed away the finer sediments, and deeper waters had finer sediments as a result of the lack of such disturbances.

Benthic Macroinvertebrates

A total of 6924 individuals of 113 benthic macroinvertebrate taxa was collected during sampling of Clarks Hill Lake in 1981 (Table D-1). Collection data are summarized in Table D-2. The fauna was composed of snail and clam-type molluscs, oligochaete worms, small crustaceans, mites, flatworms, leeches and immature insects. The immature insects and molluscs were always the primary constituents of the fauna (Table D-3).

The composition of the benthic fauna was similar to those reported from Lake Keowee (130 taxa; Duke Power, 1977) Lake Sidney Lanier (78 taxa; ESE, 1981) and from the Lake Hartwell tailrace (128 taxa excluding zooplanktonic forms; SERI, 1979). These studies may not be directly comparable, however, due to differences in substrates and sampling methodologies.

The fauna of Stations 3 and 11 were most unlike the fauna of other stations because of habitat differences. Station 3 was located in a protected cove on the South Carolina side of the lake and Station 11 was the only benthos station in the Savannah River at the Clarks Hill Dam tailwater area. Only Station 3 fauna was dominated by immature chironomid insects during every sampling period (Table D-3). Station 11 had the largest molluscan population (molluscs dominated the fauna at Station 11 during two of the three sampling periods) and, with the exception of one individual, was the station at which all benthic crustaceans were found (Table D-3).

Several trends in community composition were apparent. There was a general increase in the percentage composition of the molluscan and non-chironomid insect components of the benthic community between March and October 1981 with a concomitant general decrease in the percentage of the benthos composed of chironomid insects and annelids.

The molluscan fauna was dominated by Corbicula fluminea, the exotic Asiatic clam. Other molluscan species were rarely found at the lake stations. Station 11, in the Savannah River, was the only station with a diverse molluscan community, and it was dominated by Corbicula. Corbicula was the most abundant species collected in March and October and for the entire year (Table D-4). It was the second most abundant species in July. Corbicula, in addition to being the most abundant species, was also the most widely and evenly distributed species (Table D-5).

Since the Asiatic clam was first discovered in the western hemisphere on the north shore of the Columbia River near Knappton, Washington (Fox, 1969), it has extended its range across the United States at a phenomenal rate and achieved tremendous population numbers in natural and man-made water bodies. Where they have become established in significant numbers, Corbicula are important to nutrient cycling and energy flow through the biological system (i.e., they serve as food for fish, ducks, raccoons and even humans; Mattice and Dye, 1975). Great interest in the Asiatic clam has been stimulated by its ability to clog untreated water lines (Sinclair, 1971). Corbicula formed only a small part of the benthic community of Lake Sidney Lanier (ESE, 1981) where it was inappropriately identified as C. manilensis. There is only one species of Corbicula in North America, C. fluminea (Britlon and Morton, 1979; Smith et al., 1979). This difference is attributed to differences in sampled substrates and the likelihood of later introduction of this exotic species to Lake Sidney Lanier.

Overall, the phantom midge, Chaoborus punctipennis, was usually second ranked in abundance except in July when it was the most abundant species (Table D-4). Chaoborus generally occurred in small numbers except in three instances, all at the deep station of Station 7 where nearly 73 percent of all the Chaoborus specimens were collected. Chaoborus is an extremely common inhabitant of large lakes. It exhibits pronounced daily migration, being confined to the bottom waters and poorly-oxygenated mud during the day and migrating to the surface waters at night. Chaoborus and other members of its family are unique because of their disease-transmitting behavior and their nuisance as biters (Pennak, 1978). Chaorobus was also one of the more widely distributed species (Table D-5). This species was extremely abundant in Lake Sidney Lanier (ESE, 1981) and, as was found in Clarks Hill Lake, was most abundant at the mouths of tributaries. In these habitats, Chaoborus formed up to 94 percent of the macroinvertebrate commmunity.

Immature worms of the family Tubificidae were third ranked in abundance in 1981 (Table D-4) and were one of the more widely distributed taxa (Table D-5). Tubificid worms, in general, are the dominant worms at depths exceeding 1 meter (Pennak, 1978). The most concentrated populations of tubificids are found in polluted waters, but they are also common in clean waters. Most of the true aquatic tubificids can thrive in low concentrations of dissolved oxygen such as those found in the mud on lake bottoms (Pennak, 1978). Immature tubificids occurred on at least one occasion at every sampling station. Tubificid worms (not identified past the family level) were the most abundant taxa collected in a study on Lake Sidney Lanier (ESE, 1981).

A variety of species of chironomid insects ranked fourth through ninth (Table D-4). Chironomids are a complex group of immature fly species exhibiting preferences for a variety of microhabitats, flow regimes and substrates. Chironomids were 57 of the 113 taxa of benthic macroinvertebrates found in the Clarks Hill benthos (Table D-1), and they formed a greater portion of the benthic fauna than any other major group (Table D-3). This was similar to sampling results from a study on Lake Keowee (Ferguson and Fox, 1978) and, to a lesser extent, on Lake Sidney Lanier (COE, 1981). Because of the great number of species of chironomids found at Clarks Hill Lake, no single species was very widely distributed (Table D-5). Chironomids were found at every sampling station.

The only other non-chironomid insect that, with Chaoborus, appeared on the lists of numercially dominant or widely distributed species was Hexagenia munda (Tables D-4 and D-5). Hexagenia is a burrowing mayfly nymph common in the mud bottoms of lakes. It has large gills that move in a continual fan-like motion to maintain a constant current through its burrow. This current brings in oxygenated water and removes debris (Pennak, 1978). Hexagenia was tenth ranked in numerical abundance (Table D-4), but it was one of the more widely distributed taxa, occurring in 28 of the 54 benthic samples (Table D-5). It occurred at every lake station but did not occur at Savannah River Station 11 probably as a result of the coarse sand substrate, which is unsuitable for Hexagenia burrowing.

When the number of individuals represented by the 10 numerically dominant species for March, July and October are totaled, they account for 76.5 percent of the total number of benthic macroinvertebrates collected in 1981 (Table D-4). This illustrates the low diversity of the benthic community of Clarks Hill Lake.

The mean density of the shallow station lake samples (Stations 1, 3, 5, 7 and 9) was 2563 individuals/m^2 in March and steadily declined throughout the year to 277/m^2 in October (Figure D-2). Mean density at Station 11 followed a similar trend, beginning at 1133 individuals/m^2 in March and declining to 383/m^2 in October. When compared to the lake stations, Station 11 had lower densities except in July. This was probably a result of the presence of coarse sand substrates at Station 11. Such substrates are known to support lower densities (Hynes, 1972). Although dissolved oxygen levels are sometimes low at this station, they do not appear to be low enough to adversely affect the benthic fauna (Hart and Fuller, 1974). Mid-depth and deep locations had similar densities in March, reached their lowest density points in July and increased in density by October (Figure D-2). Because of the falling water levels encountered during 1981, shallow locations were sampled from a greater variety of substrate types than were the mid-depth or deep locations. Trends noted for the deeper locations were probably the trends encountered by all areas of the reservoir during a more normal year. Such seasonal variation is typically encountered in freshwater habitats (Hynes, 1972; Brinkhurst, 1974).

Biomass at the lake locations had dissimilar patterns of variation for each depth sampled (Figure D-3). Biomass at deep locations was always much lower than at shallow or mid-depth locations. Because of its relatively heavy body weight, *Corbicula* was the major contributor to the biomass of all the benthic samples. Variation in the density of *Corbicula* could cause a wide variation in total biomass among the locations at a single sampling station. In addition, dozens of immature *Corbicula* may have the same biomass of one mature specimen. Therefore, the general lack of clear trends in biomass variation is largely the result of the variation in density and age of *Corbicula*.

Diversity was generally highest at mid-depth stations and lowest at deep stations (Figure D-4). Diversity at all depths varied in a similar manner, being highest in March and declining throughout the year. One reason for this decline was the decline in the worm and chironomid populations noted previously. Both of these groups were abundant and diverse in March and relatively less abundant and nondiverse by October. The dominance of the fauna by *Corbicula* and *Chaoborus* also contributed to the lower October diversity values (Table D-4).

When compared to data from Lake Sidney Lanier, the benthic community in Clarks Hill Lake had lower density, higher biomass and much higher diversity (ESE, 1981). These findings were attributed to differences in community structure. The benthic community in Lake Sidney Lanier generally lacked *Corbicula*, the main contributor to biomass in Clarks Hill Lake, and was strongly dominated by tubificid worms, chironomids, and *Chaoborus*. In Lake Sidney Lanier, the very abundant tubificid worms were not identified below the family level. This caused diversity indices to appear much lower than they should have been (ESE, 1981). Differences in the benthic community structure of the two lakes were undoubtedly caused by substrate differences, size and configuration of the lakes, the number and size of tributaries entering the lakes, and effluent inputs into the lakes.

When benthic data were analyzed statistically, Stations 3 and 7 were found to have significantly greater density than Stations 1 and 9 (Appendix Table D-41). Stations 3 and 7 are both located in more sheltered waters than Stations 1 and 9 and, therefore, may be less subject to natural environmental variables such as air temperature or winds. Density at Station 5 was not significantly different from that of any other station. This was not surprising because the habitat at Station 5 was a blend of the sheltered habitats at Stations 3 and 7 and the relatively open water habitats at Stations 1 and 9 (Figure A-1).

Although the range in mean biomass values was very large, there were no statistical differences in biomass among any of the stations (Appendix Table D-42). As previously stated, variation in biomass was largely a function of the extreme variation in density and age of Corbicula. Mean biomass was greatest at Station 9 and least at Station 3.

Station 3 had significantly higher diversity than Station 7 (Appendix Table D-43). The sheltered nature of the habitat was probably responsible for the relatively high diversity at Station 3. The low diversity at Station 7 is attributed to the presence of large numbers of Chaoborus at the deep location. The other stations, 1, 5 and 9, were not significantly different from one another.

Statistical analyses recorded no significant differences in density, biomass or diversity when depths were compared (Appendix Tables D-44 through D-46). Results of these analyses were undoubtedly affected by the record fall in water level during 1981, therefore, no accurate conclusion as to station differences can be made at this time.

A comparison of mean data from sampling at Station 11 shows that benthic density, biomass and diversity are highest at the mid-stream location and lowest at the west location (Table D-6). This is largely a result of the scouring effect of higher current velocities on the west (Georgia) side of the river as determined by water release from the Clarks Hill Dam.

Drift Macroinvertebrates

A total of 3790 individuals of 121 drift macroinvertebrate taxa was collected during sampling of Clarks Hill Lake in 1981 (Table D-7). Sixty-one drift taxa were also present in the benthos (Table D-1). Collection data are summarized in Table D-8. The fauna was composed of snail- and clam-type molluscs, oligochaete worms, small crustaceans, mites, flatworms, leeches and immature insects. As is typical of freshwater communities, the immature insects, especially those of the chironomid type, dominated the drift fauna of each sampling period (Table D-9). The types of drift organisms sampled were similar to those collected in Lake Sidney Lanier where a total of 135 drift taxa were formed (ESE, 1981).

Stations showed overwhelming dominance of the fauna by chironomids except Station 1, which was never dominated by chironomids (Table D-9). It is most likely that the pronounced wind-generated turbulence in this area prevented chironomids from remaining attached to the artificial substrate samplers at this station. Station 11 also had a relatively small chironomid community, although it was larger than that of Station 1. Again, this is most likely the result of turbulence in the tailwater area of Clarks Hill Dam where Station 11 is located. The relatively low dissolved oxygen concentrations at this station do not appear to be sufficiently low to adversely affect the drift community there. As in the benthic collections, molluscs were most abundant at Station 11. Drift fauna, in general, had little success in colonizing the samplers at Stations 1 and 11 in March (Table D-9). ESE (1981) reported a similar dominance by chironomids in the drift macroinvertebrates of Lake Sidney Lanier.

Because of the overwhelming dominance of the fauna by chironomids, no clear trends of increasing or decreasing faunal segments, such as those noted in the benthic collections, were apparent.

The molluscan portion of the drift fauna was dominated by the snails *Physa* sp. (found only at Stations 1 and 11 in July) and *Valvata tricarinata simplex* (found only at Station 11 in October). Although it occurred in only two samples, *Valvata* was the most abundant drift species in October and was ranked sixth in total abundance for the year. The collected specimens were all immature and were undoubtedly recently hatched from eggs laid on the samplers by adult *Valvata* being swept downstream by the currents. Except for *Physa* and the occasional presence of recently settled *Corbicula*, other molluscan species were absent from lake stations. *Physa* sp. made the list of the ten numerically dominant species in July and was ranked tenth in numerical dominance for 1981 (Table D-10). *Corbicula* was on the list only in October. Molluscs were not common in the drift fauna reported from Lake Sidney Lanier (ESE, 1981).

Naidid worms were particularly abundant in March and declined in abundance throughout the remainder of the year. The number of tubificid worms, however, increased during the year. Four worm taxa were abundant enough to appear on the list of numerically dominant species (Table D-10). Worms were not common in the drift fauna of Lake Sidney Lanier (ESE, 1981).

Among the chironomid insects, *Limnochironomus neomodestus* was the most abundant and widely distributed species for the entire year (Tables D-10 and D-11). Other species of *Limnochironomus* also occurred in significant numbers. *Limnochironomus* sp. (*Dicrotendipes*) is a common benthic genus found in littoral areas (Merrit and Cummins, 1978). Other numerous chironomids included *Glyptotendipes* spp., *Tanytarsus* sp., *Polypedilum* spp. and Ablabesmyia spp. All of these genera are widely distributed in the United States and all are facultative in the presence of organic pollutants or heavy organic loading of aquatic systems (Table D-12). They are not restricted to polluted waters, however. A similar chironomid fauna was reported by ESE (1981). The abundant chironomids of the lake were rarely found at Station 11 in the Savannah River. All of the abundant chironomid species show a high degree of association with each other and with high nutrient and low dissolved oxygen levels such as those found in the lake (Section B).

Although rankings may have differed slightly, the taxa on the list of numerical dominants were also on the list of the most widely distributed taxa (Tables D-10 and D-11). Chironomid taxa dominate both lists. Sixty-four of the 121 drift macroinvertebrate species were chironomids (Table D-7).

The mean density of the shallow location lake samples was 513 individuals/m^2 in March and, as in the benthic fauna, declined steadily throughout the year to 96/m^2 in October (Figure D-5). Mid-depth and deep locations had highest densities in July as did Station 11. This pattern of density variation was just the reverse of that observed in the benthos (Figure D-2). As in the benthic community, the normal pattern of density variation at the shallow locations may have been disrupted by the falling water levels of 1981. Density was lowest in March at most sampling locations probably as a result of the cooler water temperatures of that month.

Biomass values decreased throughout the year and occurred over a wide range of values at shallow and mid-depth locations (Figure D-6). There was relatively little variation at the deep locations or at Station 11. Drift fauna biomass was much lower than benthic biomass because of the lack of mature, heavy-bodied molluscs. As in the benthos, deep locations had the lowest biomass. Biomass was generally lowest in October.

Station 11 and all of the lake stations were similar in that diversity values were highest in July and lowest in October (Figure D-7). Diversity at deep locations was usually lower than at shallow or mid-depth locations. In addition, drift macroinvertebrate diversity was usually lower than that of the benthic macroinvertebrates.

Statistical analysis of the drift data showed that Station 1 had significantly lower density than at any other reservoir station (Appendix Table D-47). As previously stated, this is most likely an effect of the wind-generated turbulence so prevalent at this station. The other lake stations were not significantly different from each other despite the fairly wide range in mean density. Station 9 had the highest mean density and Stations 5 and 7 were very similar. Considering the high density of the benthic fauna at Station 3, it was somewhat surprising to find a relatively low density drift fauna there. This contradiction is probably explained by the sheltered geography of Station 3. With shelter from the wind, there is less turbulence to keep the drift fauna up in the water column. In this manner, settled macroinvertebrates lost from the drift fauna augment benthic faunal density.

In addition to its low density, Station 1 also had significantly lower biomass than other lake stations (Appendix Table D-48). Station 3 had the highest mean biomass primarily as a result of the presence of small numbers of large naidid worms in March and July. Comparison of the low drift mean biomass values with the much higher benthic means emphasizes the importance of the contribution of a well-developed molluscan fauna to energy flow through the benthic community, particularly the importance of the dominant benthic mollusc Corbicula fluminea.

Mean diversity values for the drift fauna were much lower than those of the benthic fauna (Appendix Tables D-43 and D-49). Station 1 had significantly lower mean diversity than any other station and Station 3 had the highest mean diversity. The order of ranked means by station for both drift biomass and drift diversity was identical (Appendix Tables D-48 and D-49).

When compared to data from Lake Sidney Lanier, the drift fauna of Clarks Hill Lake had lower density, similar biomass, and higher diversity (ESE, 1981). These findings were attributed to differences in community structure, the community at Lake Sidney Lanier being dominated by chironomids and Chaoborus to a much greater degree than in Clarks Hill Lake. Differences in the community structure of the two lakes were undoubtedly caused by the size and configuration of the lakes. The number and size of tributaries entering the lakes, effluent inputs into the lakes, and circulation patterns of the lakes.

Statistical analyses revealed no significant differences in density, biomass or diversity when depths were compared (Appendix Tables D-50 through D-52). Results of this analysis were undoubtedly affected by the record fall in water level during 1981, so no accurate conclusion as to station differences can be made at this time.

Mean drift density and biomass were highest on the east side of the Savannah River at Station 11 (Table D-6). Diversity was highest at the mid-stream location and density, biomass and diversity were lowest on the west (Georgia) side of the river. Current velocities were highest on the west wide of the river and allowed the east side to accumulate a drift fauna while washing away most of the drift organisms that attempted to colonize samplers on the west side.

SUMMARY

In March, sediments were finer-grained as depth increased. All lake stations had medium sand substrates except Station 6, which had a very fine sand substrate. Mean grain sizes at the lake stations in September were much finer than those reported in March. Lake Station 6, however, exhibited a high degree of stability and continued to have very fine sand substrates. River Stations 11 and 12 varied only slightly between the two sampling periods.

The benthic macroinvertebrate community of Clarks Hill Lake is considered one of low density and diversity. The community is dominated by Corbicula fluminea and, secondarily, by immature tubificid worms and several species of chironomid insects. Crustaceans and non-chironomid insects are poorly represented in the fauna. Although 1981 trends in density, biomass and diversity variation may have been disrupted by the record fall in water level, it appears that these community parameters are generally highest in the spring and lowest in mid-summer. Such seasonal variation is typically encountered in freshwater habitats (Hynes, 1972; Brinkhurst, 1974). Compared to the other lake stations, Station 9, located in an area that will become the tailwaters of the Richard B. Russell Dam, had the second lowest density and diversity but had the highest biomass.

Statistical analyses of the benthic data showed no significant differences among biomass values at the lake stations. Stations 3 and 7 were found to have significantly greater densities than Stations 9 or 1. Station 3 was found to have significantly greater diversity than Station 7. All of these statistical differences were related to habitat differences, particularly at Station 3, which is in a sheltered cove. No statistical differences were found when benthic community parameters were compared by depth. However, this may have been a function of the record fall in water level during 1981.

The drift macroinvertebrate fauna also had low density and diversity. Biomass, as expected, was much lower than that of the benthic community as the result of a lack of molluscs. These organisms are heavy contributors to benthic biomass, but they were not a part of the drift fauna. The drift community was dominated by an association of several species of chironomid insects, the environmental requirements of which are all similar. While all of these chironomid species are frequently associated with organically polluted waters, they are not restricted to such habitats. Crustaceans and non-chironomid insects were poorly represented in the drift fauna. Although disruptions of natural patterns of density, biomass and diversity variation may have taken place in 1981 because of the record fall in the water level, it appears that the drift fauna was at its peak in mid-summer, when it supplements the benthic community, and at its low point in the fall. Contrary to the benthos at Station 9, the drift macroinvertebrate community there had highest density and second highest biomass and diversity of all the lake stations.

Statistical analyses indicated that the drift fauna was similar at all lake stations except Station 1. The fauna there was adversely affected by wind-generated turbulence that prevented the colonization of the artificial substrate samplers placed there. Turbulence also affected the Savannah River Station 11. There, the drift fauna was adversely affected by the turbulence of water release from the Clarks Hill Dam. Effects are primarily located on the west (Georgia) side of the river. No statistical differences were found when drift community parameters were compared by depth.

When compared with the benthic and drift faunas of another Georgia lake, Lake Sidney Lanier, the benthic fauna of Clarks Hill Lake had generally lower density, higher biomass, and higher diversity. Differences were attributed to different community structures which were caused by the different physical characteristics of the two lakes.

LITERATURE CITED

APHA (American Public Health Association). 1980. Standard methods for the examination of water and wastewater, 15th ed. American Public Health Assoc., Washington, D.C. 1308 pp.

Beck, W.M. 1976. Biology of the larvel chironomids. Florida Department of Environmental Regulation Technical Series. 2(1):1-58.

__________. 1977. Environmental requirements and pollution tolerance of common freshwater Chironomidae. Environmental Protection Agency, Cincinnati, Ohio 260 pp.

Brinkhurst, R.O. 1964. Studies on the North American aquatic Oligochaeta. I. Naididae and Opistocystidae. Proceedings of the Academy of Natural Sciences (Philadelphia) 116(5):195-230.

__________. 1965. Studies on the North American aquatic Oligochaeta. II. Tubificidae. Proceedings of the Academy of Natural Sciences (Philadelphia) 117(4):117-172.

__________. 1974. The benthos of lakes. St. Martin's Press, New York. 189 pp.

Brinkhurst, R.O., and D.G. Cook. 1966. Studies on the North American aquatic Oligochaeta. III. Lumbriculidae and additional notes and records of other families. Proceedings of the Academy of Natural Sciences (Philadelphia) 118(1):1-33.

Britlon, J.C., and B. Morton. 1979. Corbicula in North America; The evidence reviewed and evaluated. Pages 249-288, in J.C. Britlon, ed. Proceedings, First International Corbicula Symposium. Texas Christian University Press, Ft. Worth.

Brown, H.P. 1972. Aquatic dryopoid beetles (Coleoptera) of the United States. U.S. Environmental Protection Agency, Washington, D.C. 82 pp.

Burch, J.B. 1972. Freshwater sphaeriacean clams (Mollusca: Pelecypoda) of North America. U.S. Environmental Protection Agency, Washington, D.C. 31 pp.

__________. 1973. Freshwater unionacean clams (Mollusca: Pelecypoda) of North America. U.S. Environmental Protection Agency, Washington, D.C. 176 pp.

Burks, B.D. 1953. The mayflies, or Ephemeroptera, of Illinois. Bulletin of the Illinois Natural History Survey 26(1):1-216.

LITERATURE CITED (continued)

COE (U.S. Army Corps of Engineers). 1981. Water quality management study, Lake Sidney Lanier, Georgia. Final Report. Prepared by Environmental Science and Engineering for U.S. Army Corps of Engineers, Mobile District.

Duke Power Company. 1977. Oconee Nuclear Station: Environmental Summary Report 1971-1976. Addendum A. Compilation of data collected by Southeast Reservoir Investigations in Keowee Reservoir, 1972-1975. Special report to Duke Power Co., Charlotte, N.C.

EPA (Environmental Protection Agency). 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. C.I. Weber (ed.), EPA 670/4-73-001. U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio.

Edmunds, G.F., S.L. Jensen, and L. Berner. 1976. The mayflies of North and Central America. University of Minnesota Press, St. Paul. 376 pp.

Ferguson, V.M., and R.C. Fox. 1978. A comparison of aquatic insects in natural inlets with those in the heated effluent from the Oconee Nuclear Station-littoral zone. Journal of the Georgia Entomological Society 13(3):202-213.

Folk, R.L. 1961. Petrology of sedimentary rocks. Hemphill's, Austin, Texas. 127 pp.

Fox, R.O. 1969. The Corbicula story: A progress report. Presented at Second Annual Meeting of the Western Society of Malacologists. San Diego, Calif. 19 June 1969.

Frison, T.H. 1935. The stoneflies, or Plecoptera, of Illinois. Bulletin of the Illinois Natural History Survey 20(4):281-471.

Fullner, R.W. 1971. A comparison of macroinvertebrates collected by basket and modified multiple-plate samplers. Journal of the Water Pollution Control Federation 43(3):494-499.

Hart, C.W., and S.L.H. Fuller. 1974. Pollution ecology of freshwater invertebrates. Academic Press, New York. 389 p.

Hester, F.E., and J.S. Dendy. 1962. A multiple-plate sampler for aquatic macroinvertebrates. Transactions of the American Fishery Society 91(4):420-421.

Hiltunen, J.K., and D.J. Klemm. 1980. A guide to the Naididae (Annelida: Clitellata: Oligochaeta) of North America. U.S. Environmental Protection Agency, Cincinnati, Ohio. 47 pp.

LITERATURE CITED (continued)

Hobbs, H.H., Jr. 1976. Crayfishes (Astacidae) of North and Middle America. U.S. Environmental Protection Agency, Cincinnati, Ohio. 173 pp.

Holsinger, J.R. 1972. The freshwater amphipod crustaceans (Gammaridae) of North America. U.S. Environmental Protection Agency., Washington, D.C. 89 pp.

Hynes, H.B.N. 1972. Ecology of running waters. University of Toronto Press. 555 pp.

Lloyd, J., J.H. Zar, and J.R. Karr. 1968. On the calculation of information-theoretical measures of diversity. American Midland Naturalist 72(2):257-272.

Mason, W.T., Jr. 1971. An introduction to the identification of chironomid larvae. U.S. Environmental Protection Agency, Cincinnati, Ohio. 90 pp.

Mattice, J.S., and L. Dye. 1975. Thermal tolerance of the adult Asiatic clam. Presented at the Second Thermal Ecology Symposium. Augusta, Georgia. 25 April 1975.

Merritt, R.W., and K.W. Cummins. 1978. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Company, Dubuque, Iowa. 441 pp.

Needham, J.G., and M.H. Westfall. 1955. A manual of the dragonflies of North America (Anisoptera). University of California Press, Berkeley. 615 pp.

Oliver, D.R., D. McClymont, and M.E. Roussel. 1978. A key to some larvae of chironomidae (Diptera) from the MacKenzie and Porcupine River watersheds. Fisheries and Marine Service Technical Report No. 791. F&MS, Winnipeg. 73 pp.

Parrish, F.K. 1975. Keys to water quality indicative organisms of the southeastern United States. U.S. Environmental Protection Agency, Cincinnati, Ohio. 195 pp.

Pennak, R.W. 1978. Freshwater invertebrates of the United States. 2nd ed. Wiley-Interscience, New York, N.Y. 803 pp.

Royce, C.F. 1970. An introduction to sediment analysis. Arizona State University Press, Tempe. 180 pp.

Roback, S.S. 1974. Insects. In C.W. Hart and S.L.H. Fuller, eds. Pollution ecology of freshwater invertebrates. Academic Press, New York. 389 pp.

LITERATURE CITED (continued)

Ross, H.H. 1944. The caddisflies, or Trichoptera, of Illinois. Bulletin of the Illinois Natural History Survey. 23(1):1-326.

SERI (Southeast Reservoir Investigations). 1979. Hartwell Reservoir Tailwater Studies, special purpose report. Southeast Reservoir Investigations, U.S. Fish and Wildlife Service. Clemson, S.C.

Simpson, K.W., and R.W. Bode. 1980. Common larvae of Chironomidae (Diptera) from New York State streams and rivers. Bulletin No. 439 New York State Museum, State Education Department, Albany, New York. 105 pp.

Sinclair, R.M. 1971. Annotated bibliography on the exotic bivalve Corbicula in North America, 1900-1971. Sterkiana 43:11-18.

Smith, M.H., J. Britton, P. Burke, R.K. Chesser, M.W. Smith, and J. Hagen. 1979. Genetic variability in Corbicula, an invading species. Pages 227-242, in J.C. Britton, ed. Proceedings, First International Corbicula Symposium. Texas Christian University Press, Ft. Worth.

USGS (United States Geological Survey). 1977. Methods for collection and analysis of aquatic biological and microbiological samples. United States Geological Survey, Washington, D.C.

Wiggins, G.B. 1977. Larvae of the North American caddisfly genera (Trichoptera). University of Toronto Press. 401 pp.

Williams, G.E., III. 1974. New technique to facilitate handpicking macrobenthos. Transactions of the American Microscopical Society 93(2):220-226.

Williams, W.C. 1976. Freshwater isopods (Asellidae) of North America. U.S. Environmental Protection Agency, Cincinnati, Ohio. 45 pp.

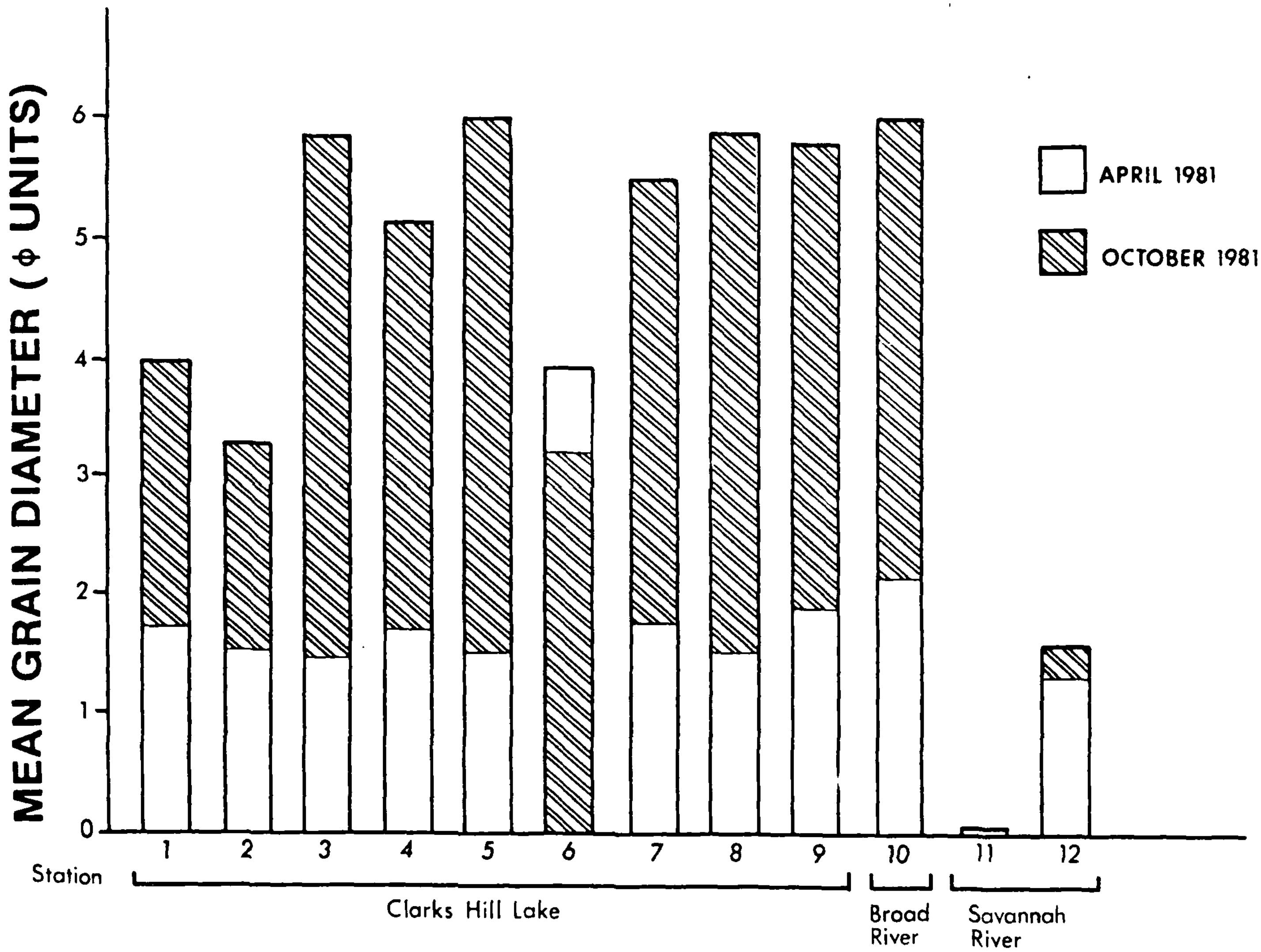


Figure D-1. Comparison of sediment mean grain diameters at biological/chemical sampling stations, Clarks Hill Lake, 1981.

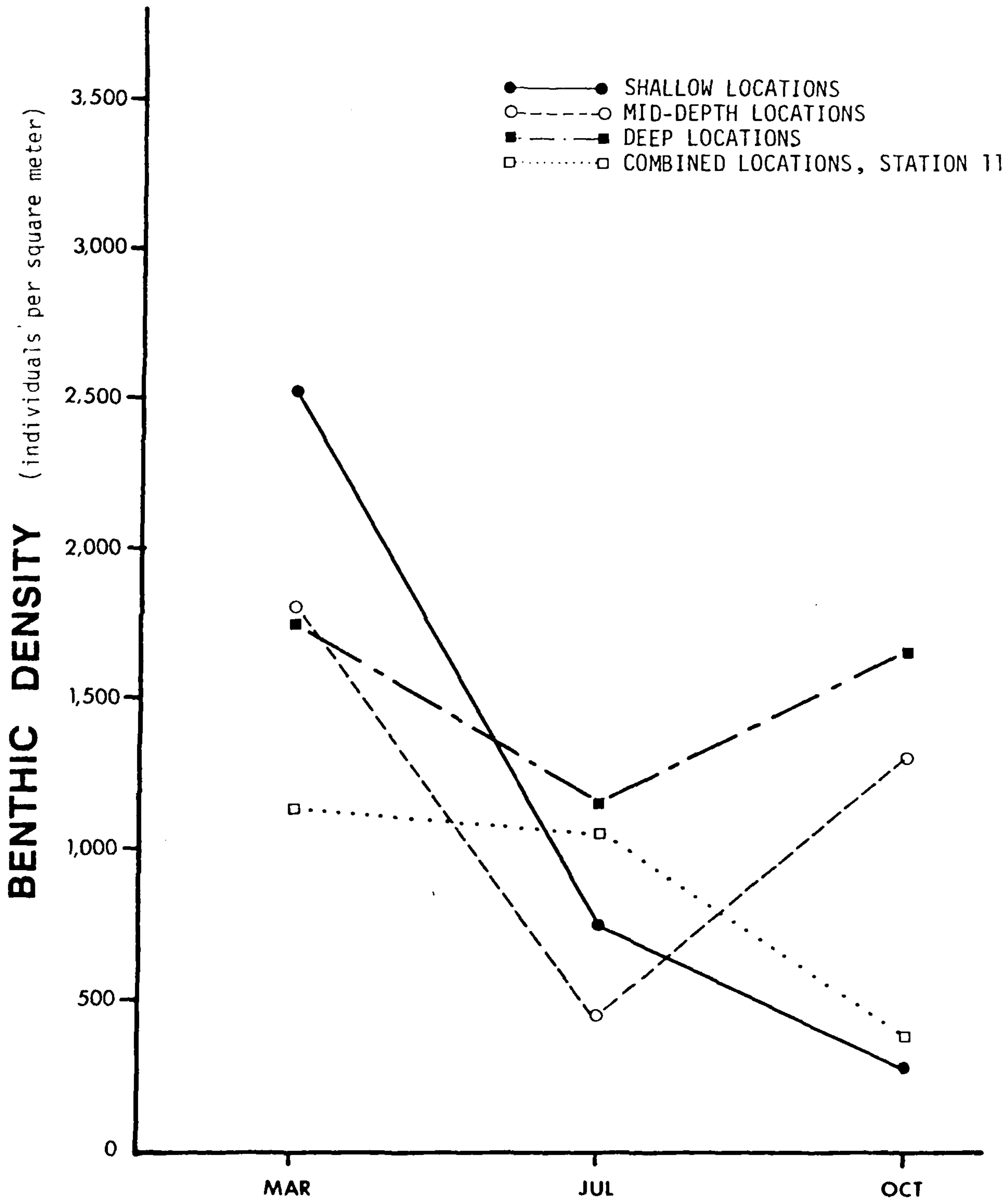


Figure D-2. Benthic mean density at Stations 1, 3, 5, 7 and 9 combined at shallow, mid-depth and deep locations and Station 11, Clarks Hill Lake, 1981.

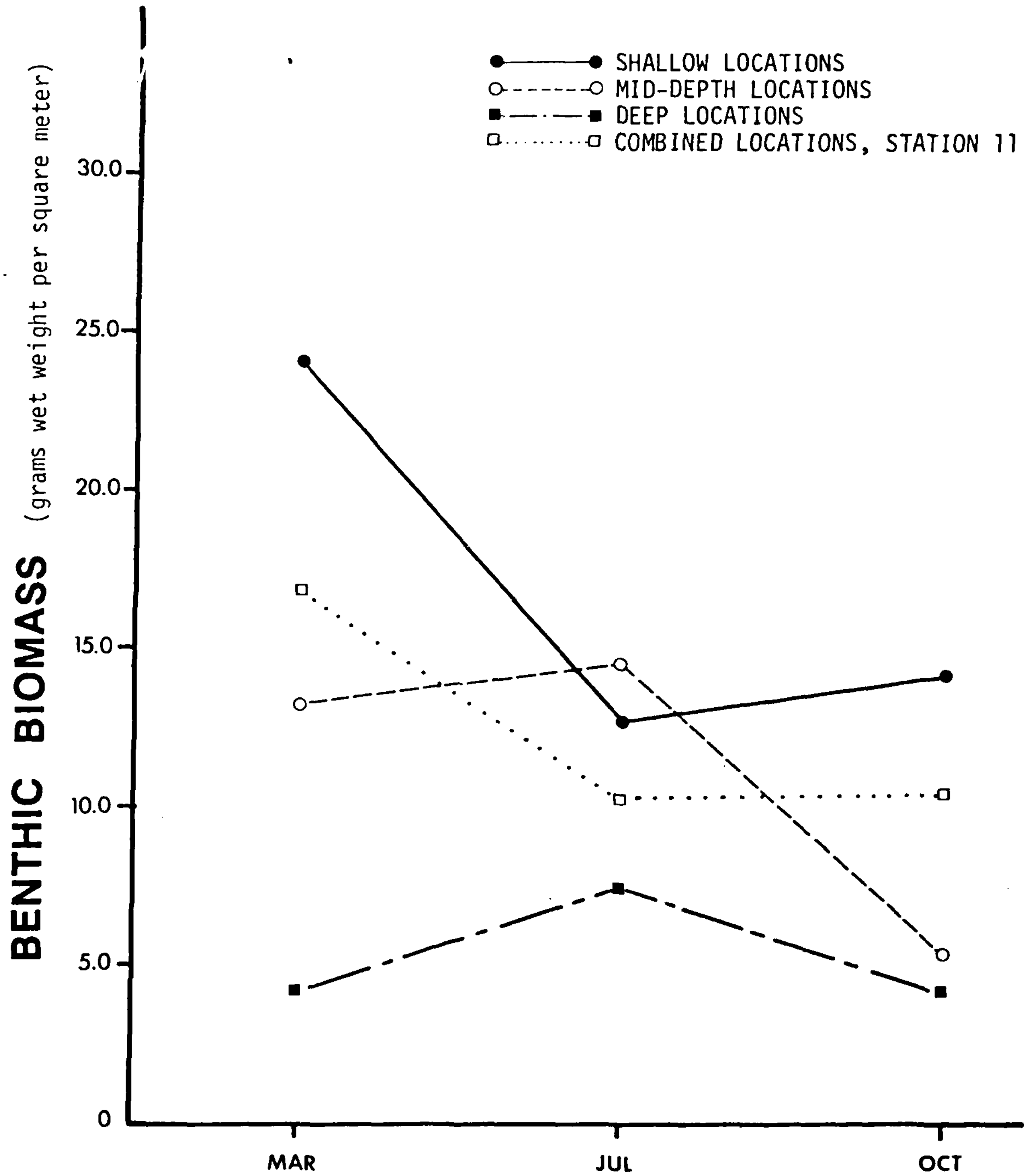


Figure D-3. Benthic mean biomass at Stations 1, 3, 5, 7 and 9 combined at shallow, mid-depth and deep locations and Station 11, Clarks Hill Lake, 1981.

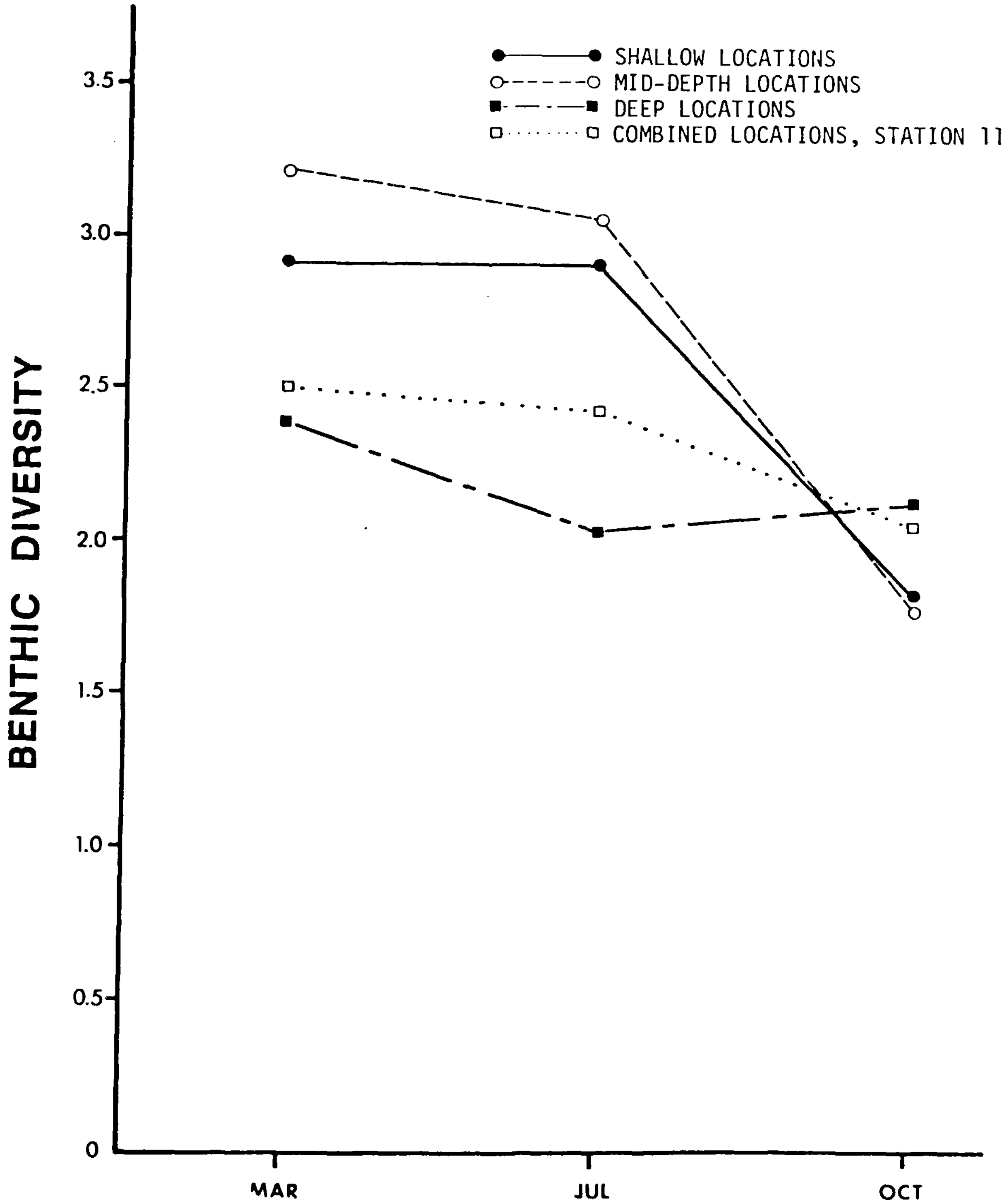


Figure D-4. Benthic diversity at Stations 1, 3, 5, 7 and 9 combined at shallow, mid-depth and deep locations and Station 11, Clarks Hill Lake, 1981.

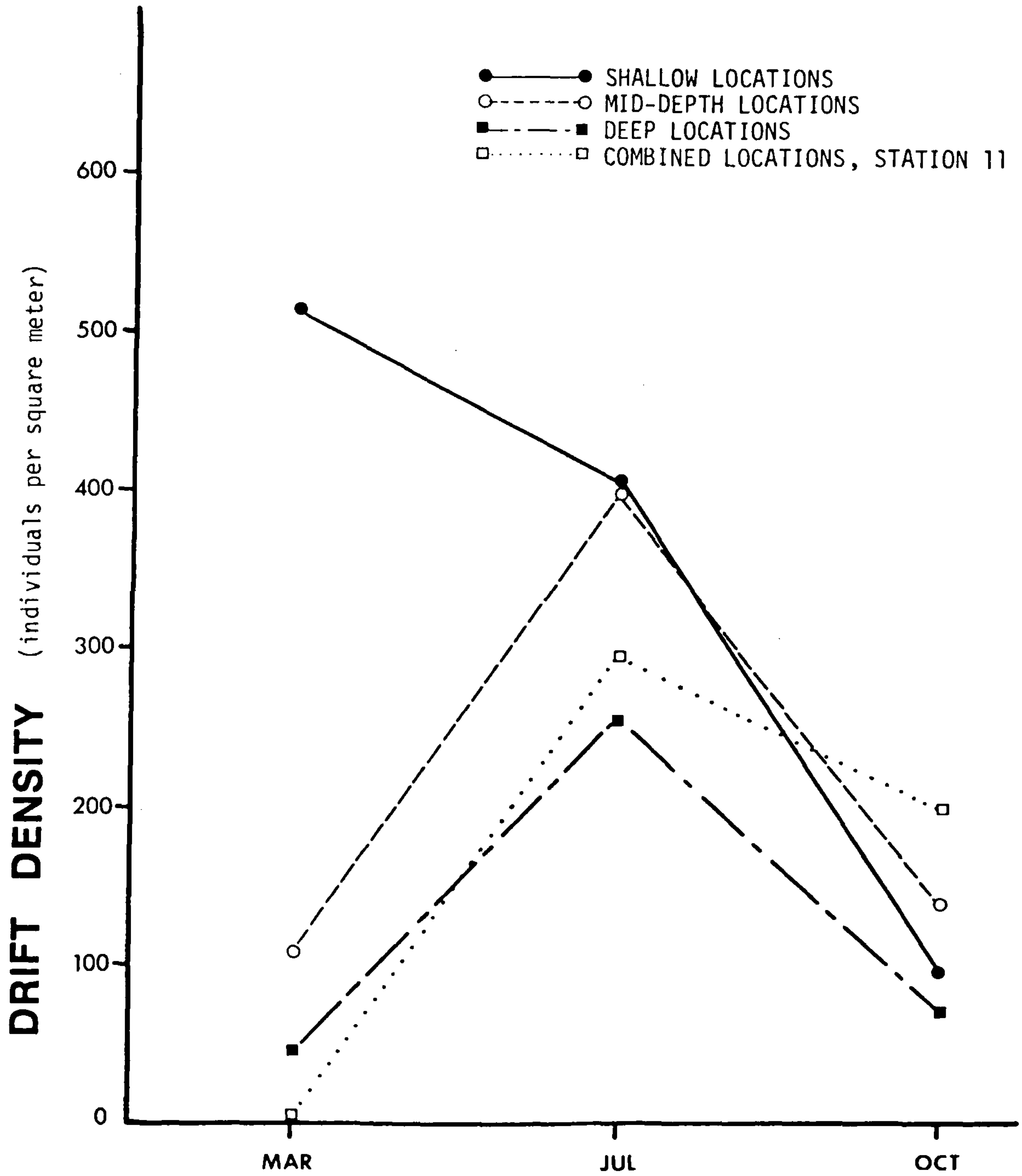


Figure D-5. Drift macroinvertebrate density at Stations 1, 3, 5, 7 and 9 combined at shallow, mid-depth and deep locations and Station 11, Clarks Hill Lake, 1981.

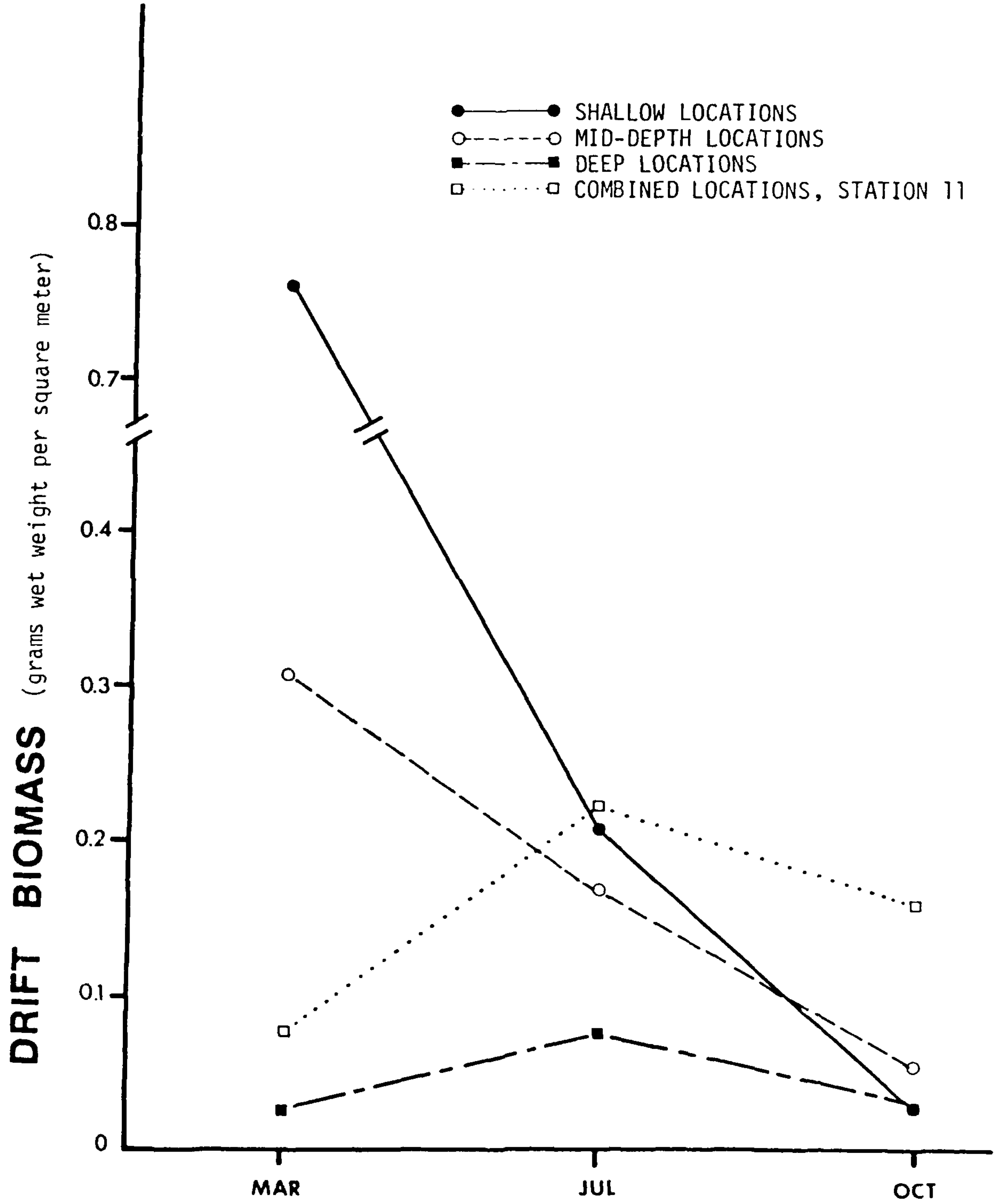


Figure D-6. Drift mean biomass at Stations 1, 3, 5, 7 and 9 combined at shallow, mid-depth and deep locations and Station 11, Clarks Hill Lake, March, July and October 1981.

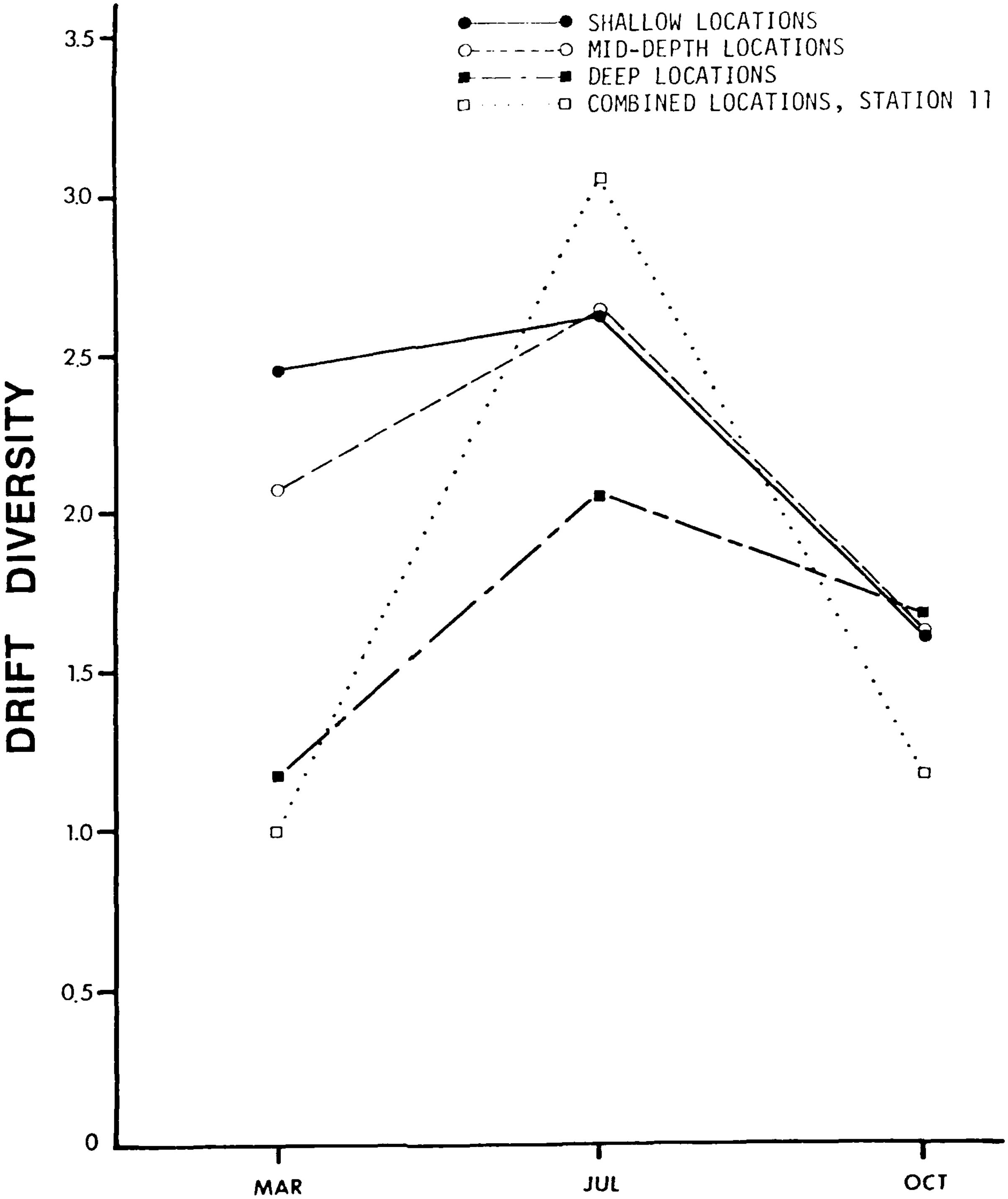


Figure D-7. Drift macroinvertebrate diversity at Stations 1, 3, 5, 7 and 9 combined at shallow, mid-depth and deep locations and Station 11, Clarks Hill Lake, March, July and October 1981.

TABLE D-1

BENTHIC MACROINVERTEBRATE TAXONOMIC LIST
CLARKS HILL LAKE
1981

Phylum Platyhelminthes
Class Turbellaria
unidentified Planariidae
unidentified sp. 1*

Phylum Ectoprocta
Fredericella sultana*
Pectinatella magnifica*
Plumatella repens*

Phylum Annelida
Class Oligochaeta
Arcteonais lomondi*
Aulodrilus pigueti
Branchiura sowerbyi*
Dero abranchiata
D. nivea
D. vega*
Ilyodrilus templetoni*
Limnodrilus hoffmeisteri
Lumbriculidae sp.
Naididae sp.*
Nais pardalis
N. variabilis
Potamothrix vegjovskyi*
Pristina longiseta
Slavina appendiculata
Tubifex tubifex
Tubificidae w/ hair setae*
Tubificidae w/o hair setae
unidentified sp. 1*
Class Hirudinea
Placobdella parasitica*

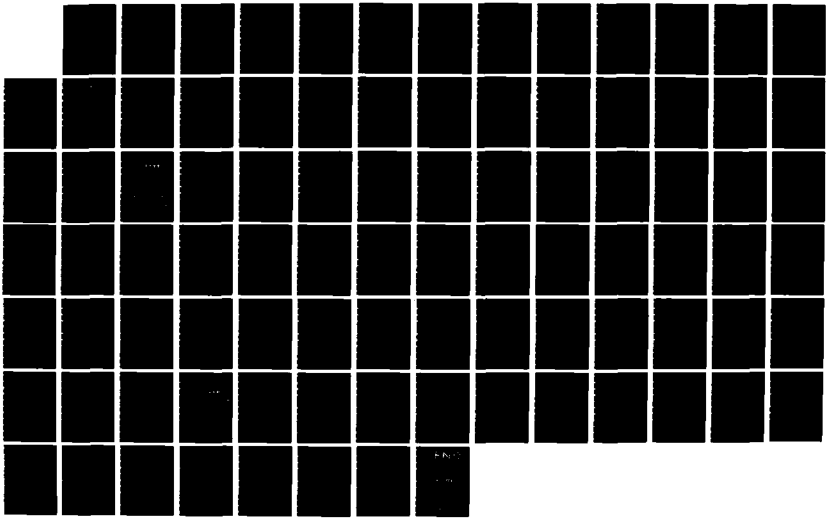
Phylum Arthropoda
Class Arachnoidea
Arrenurus sp.*
Limnesia sp.*
Class Crustacea
Hyalella azteca
Lirceus fontinalis
Class Insecta
Order Diptera
Ablabesmyia annulata*
A. cinctipes*
A. mallochi
A. ornata

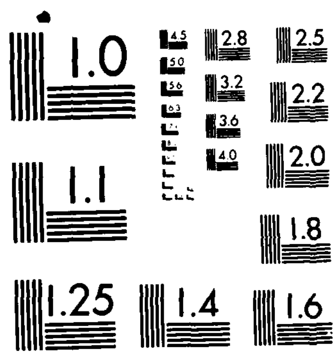
Order Diptera
Ablabesmyia parajanta
A. tarella*
Bezzia sp. 1
Bezzia sp. 2
Bezzia sp. 3*
Bezzia sp. 4*
Chaoborus punctipennis
Chironomus decorus gr.
C. plumosus gr.
Cladopelma sp.*
Cladotanytarsus sp.
Coelotanypus concinnus*
C. scapularis*
C. tricolor*
Conchapelopia sp.*
Cricotopus tremulus gr
Cryptochironomus blarina*
C. digitatus*
C. fulvus
C. sorex*
Cryptotendipes sp. 1*
Cryptotendipes sp. 2*
Djalmabatista pulcher*
Einfeldia sp.*
Endochironomus nigricans
Epoicocladius flavens*
Glyptotendipes sp.
Glyptotendipes lobiferus
Harnischia curtilamellata*
Limnochironomus leucoscelis
L. neomodestus
Micropsectra sp.
Nanocladius rectinervis
Nilodorum sp.
Nilothauma bicornis
Orthocladius sp.
O. obumbratus
Orthocladius-Cricotopus gr.
sp. 1
Pagastiella ostansa*
Parachironomus carinatus
Paratanytarsus sp.
Phaenopsectra vittata*
Polypedilum halterale
P. scalaenum
Procladius sp.

CHI
TABLED-1

AD-A161 970 CLARKS HILL LAKE WATER QUALITY STUDY(U) APPLIED BIOLOGY 2/2
INC DECATUR GA JUN 82 DACW21-81-C-0011

UNCLASSIFIED F/G 8/8 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE D-1
(continued)
BENTHIC MACROINVERTEBRATE TAXONOMIC LIST
CLARKS HILL LAKE
1981

Order Diptera
- Procladius bellus
- P. sublettei*
- Procladius sp. 3
- Procladius sp. 4*
- Psectrocladius psilopterus
- Pseudochironomus fulviventris*
- Stempellina sp.*
- Stictochironomus devinctus?*
- Tanytarsus sp.
- unknown sp. 3 (Chironomini)*
- unknown sp. 4 (Orthocladiinae)*
- Xenochironomus xenolabis

Order Trichoptera
- Hydropsychidae sp.
- Ochrotrichia sp.
- O. inconspicua*
- Orthotrichia americana
- Oxyethira sp.
- Phylocentropus sp.*
- Polycentropus sp.

Order Ephemeroptera
- Caenis diminuta
- Hexagenia munda

Order Ephemeroptera
- Stenonema terminatum*

Order Odonata
- Coenagrionidae sp.*
- Dromogomphus spoliatus*

Order Coleoptera
- Dubiraphia sp.*

Order Megaloptera
- Sialis sp.

Phylum Mollusca

Class Gastropoda
- Amnicola limosa
- Gyraulus sp. *
- Physa integra
- Valvata tricarinata simplex
- unknown genus No. 1*

Class Pelecypoda
- Corbicula fluminea
- Sphaerium partumeium*
- S. striatinum*
- immature Sphaeriidae

---

*Taxa not found in the drift macroinvertebrate collection.

No asterisk means that the taxon was found in both benthic and drift macroinvertebrate collections.

CHI
TABLED-1A

TABLE D-2

SUMMARY OF BENTHIC MACROINVERTEBRATE COLLECTION DATA
CLARKS HILL LAKE
1981

	Density (no./m^2)								
	March			July			October		
Station	Shallow[a]	Mid	Deep[b]	Shallow[a]	Mid	Deep[b]	Shallow[a]	Mid	Deep[b]
1	78	1186	366	959	481	554	88	57	210
3	5360	6084	2560	762	1126	434	575	3605	804
5	2083	240	1464	727	290	2031	88	1750	115
7	3285	688	3288	880	174	2160	555	1080	7078
9	2001	763	1049	381	247	577	76	39	68
11	362	2332	706	1743	1414	20	184	649	317
	Biomass (g/m^2)								
1	0.038	15.096	2.371	2.476	0.870	1.902	0.164	20.822	12.745
3	5.832	11.003	3.509	4.751	2.008	1.434	9.623	0.590	3.479
5	44.446	6.730	9.685	24.962	12.419	7.983	34.069	2.804	0.632
7	12.935	1.644	3.327	0.880	57.161	1.902	20.211	2.727	3.899
9	60.115	31.157	1.845	31.195	0.344	24.503	6.804	0.156	0.325
11	15.163	34.446	1.157	20.507	10.325	0.392	0.038	10.576	21.088

TABLE D-2
(continued)
SUMMARY OF BENTHIC MACROINVERTEBRATE COLLECTION DATA
CLARKS HILL LAKE
1981

Station	Diversity (no./m^2)								
	March			July			October		
	Shallow[a]	Mid	Deep[b]	Shallow[a]	Mid	Deep[b]	Shallow[a]	Mid	Deep[b]
1	1.57	3.69	3.39	3.05	3.41	2.11	2.31	0.67	2.11
3	3.51	3.47	3.52	2.77	3.49	3.70	1.81	3.26	2.71
5	3.14	2.75	1.58	3.07	3.46	1.83	2.43	1.19	2.07
7	2.98	2.55	1.19	1.35	2.54	0.27	2.54	2.25	1.49
9	3.40	3.55	2.32	2.69	2.35	2.23	0.00	1.51	2.25
11	2.68	2.50	2.35	2.88	3.37	0.99	1.76	2.25	2.14

[a]At Station 11, the data are for the East station.

[b]At Station 11, the data are for the West station.

CHI
TABLED-2

TABLE D-3

BENTHIC MACROINVERTEBRATE COMMUNITY STRUCTURE BY
PERCENTAGE COMPOSITION OF MAJOR TAXONOMIC GROUPS
CLARKS HILL LAKE
1981

		Percentage composition						
Station	Month	Molluscs	Crustaceans	Annelids	Miscellaneous	Chironomid insects	Non-chironomid[a] insects	Total specimens
1	March	10.0	0.0	13.1	0.6	63.4	12.9	170
	July	24.9	0.0	30.3	0.9	36.6	7.2	209
	October	37.5	0.0	8.2	0.0	16.6	37.7	37
3	March	19.8	0.0	7.5	0.0	60.3	12.4	1464
	July	9.9	0.0	0.0	0.0	69.1	21.0	243
	October	35.5	0.0	0.0	2.7	38.7	23.1	522
5	March	25.0	0.0	5.0	3.0	32.6	34.3	396
	July	8.8	0.3	2.5	0.0	39.7	48.7	319
	October	74.9	0.0	0.0	0.5	12.3	12.3	204
7	March	6.8	0.0	23.7	0.8	27.6	41.1	760
	July	22.3	0.0	5.4	0.0	5.7	66.6	336
	October	24.9	0.0	0.8	0.3	19.0	55.0	912
9	March	11.5	0.0	10.3	0.0	47.9	30.3	399
	July	21.4	0.0	2.4	1.6	41.2	33.4	126
	October	62.3	0.0	0.0	0.0	26.8	10.9	19
11	March	55.6	2.8	22.5	5.1	12.4	1.6	356
	July	20.2	8.4	32.5	2.4	35.9	0.6	332
	October	69.1	0.0	6.8	0.0	22.4	1.7	120

TABLE D-3
(continued)
BENTHIC MACROINVERTEBRATE COMMUNITY STRUCTURE BY
PERCENTAGE COMPOSITION OF MAJOR TAXONOMIC GROUPS
CLARKS HILL LAKE
1981

		Percentage composition						
Station	Month	Molluscs	Crustaceans	Annelids	Miscellaneous	Chironomid insects	Non-chironomid[a] insects	Total specimens
All stations combined	March	19.8	0.3	12.8	1.0	44.1	22.0	3545
	July	17.4	1.9	12.8	0.8	35.9	31.2	1565
	October	37.2	0.0	1.0	1.0	24.2	36.6	1814
1981	All months combined	23.8	0.5	9.7	1.0	37.1	27.9	6924

[a]Includes *Bezzia* spp. and *Chaoborus punctipennis*.

CHI
TABLED-3

TABLE D-4

COMPARISON OF THE TEN NUMERICALLY DOMINANT BENTHIC SPECIES IN EACH SAMPLING PERIOD
CLARKS HILL LAKE
1981

Rank	March		July		October		Total	
	Taxon	Number of specimens	Taxon	Number of specimens	Taxon	Number of specimens	1981	Number of specimens
1	Corbicula fluminea (C)[a]	586	Chaoborus punctipennis (F)	408	Corbicula fluminea (C)	655	Corbicula fluminea (C)	1500
2	Chaoborus punctipennis (F)	546	Corbicula fluminea (C)	259	Chaoborus punctipennis (F)	523	Chaoborus punctipennis (F)	1328
3	Immature Tubificidae (W)	296	Immature Tubificidae (W)	163	Pseudochironomus fulviventris (F)	83	Immature Tubificidae (W)	469
4	Cladotanytarsus sp. (F)	245	Xenochironomus sp. (F)	77	Chironomus plumosus (F)	68	Pseudochironomus fulviventris (F)	285
5	Glyptotendipes sp. (F)	202	Coelotanypus tricolor (F)	56	Coelotanypus tricolor (F)	52	Cladotanytarsus sp. (F)	247
6	Tanytarsus sp. (F)	198	Coelotanypus concinnus (F)	53	Hexagenia munda (M)	48	Tanytarsus sp. (F)	215
7	Pseudochironomus fulviventris (F)	196	Cricotopus tremulus (F)	40	Bezzia sp. 2 (F)	46	Glyptotendipes sp. (F)	202
8	Cryptochironomus fulvus (F)	138	Polypedilum scalaenum (F)	37	Coelotanypus concinnus (F)	39	Cryptochironomus fulvus (F)	172
9	Bezzia sp. 1 (F)	93	Paratanytarsus sp. (F)	34	Ablabesmyia annulata (F)	20	Coelotanypus tricolor (F)	166
10	Hexagenia munda (M)	85	Procladius sublettei (F)	33	Xenochironomus sp. (F)	20	Hexagenia munda (M)	156

[a] (C) = clam; (F) = fly larva or pupa; (M) = mayfly nymph; (W) = worm.

CHI
TABLED-4

TABLE D-5

COMPARISON OF THE TEN MOST WIDELY DISTRIBUTED BENTHIC SPECIES IN EACH SAMPLING PERIOD[a]
CLARKS HILL LAKE
1981

	March		July		October		Total	
ık	Taxon	Number of samples	Taxon	Number of samples	Taxon	Number of samples	1981	Number of samples
	Corbicula fluminea (C)[b]	18	Corbicula fluminea (C)	16	Corbicula fluminea (C)	18	Corbicula fluminea (C)	52
	Immature Tubificidae (W)	13	Immature Tubificidae (W)	11	Chaoborus punctipennis (F)	10	Immature Tubificidae (W)	28
	Cryptochironomus fulvus (F)	13	Coelotanypus concinnus (F)	11	Hexagenia munda (M)	9	Hexagenia munda (M)	28
	Chironomus decorus (F)	13	Procladius sublettei (F)	10	Cryptochironomus fulvus (F)	8	Cryptochironomus fulvus (F)	28
	Bezzia sp. 1 (F)	11	Chaoborus punctipennis (F)	8	Coelotanypus concinnus (F)	7	Chaoborus punctipennis (F)	27
	Hexagenia munda (M)	11	Hexagenia munda (M)	8	Coelotanypus tricolor (F)	5	Procladius sp. 1 (F)	21
	Procladius sublettei (F)	10	Harnischia curtilamellata (F)	8	Bezzia sp. 2 (F)	5	Tanytarsus sp. (F)	19
	Tanytarsus sp. (F)	9	Tanytarsus sp. (F)	8	Chironomus plumosus (F)	5	Coelotanypus concinnus (F)	18
	Chaoborus punctipennis (F)	9	Cryptochironomus fulvus (F)	7	Oecetis inconspicum	5	Coelotanypus tricolor (F)	17
	Pseudochironomus fulviventris (F)	8	Coelotanypus scapularis (F)	7	Pseudochironomus fulviventris (F)	5	Pseudochironomus fulviventris (F)	16

ıe most widely distributed organism was determined by the number of samples in which the organism was found. Organisms could occur in a maxi-ım of 18 samples from each sampling period and a maximum annual total of 54 samples.

:) = clam; (F) = fly larva or pupa; (M) = mayfly nymph; (W) = worm; (T) = caddis fly larva.

TABLE D-6

COMPARISON OF BENTHIC AND DRIFT MACROINVERTEBRATE
MEAN COLLECTION DATA AT SAVANNAH RIVER STATION 11
CLARKS HILL LAKE
1981

Community parameter	Collection	Annual mean/station		
		West	Mid-river	East
Density ($no./m^2$)	Benthos	189	1354	1033
	Drift	53	118	328
Biomass (g/m^2)	Benthos	5.198	21.953	10.747
	Drift	0.029	0.112	0.268
Diversity	Benthos	1.81	2.67	2.49
	Drift	0.87	2.06	1.63

CHI
TABLE D-6

TABLE D-7

DRIFT MACROINVERTEBRATE TAXONOMIC LIST
CLARKS HILL LAKE
1981

Phylum Platyhelminthes
- Planaria sp.*
- unidentified Planariidae
- unidentified Tricladida*

Phylum Annelida

Class Oligochaeta
- Allonais pectinata*
- Amphichaeta americana*
- Aulodrilus pigueti
- Dero sp.*
- D. abranchiata
- D. nivea
- Enchytraeidae sp.*
- Limnodrilus hoffmeisteri
- Lumbriculus variegatus*
- Lumbriculidae sp.
- Nais sp.*
- N. behningi*
- N. bretscheri*
- N. communis*
- N. elinguis*
- N. pardalis
- N. variabilis
- Pristina longiseta longiseta
- Rhyacodrilus sodalis*
- Slavina appendiculata
- Stylaria lacustris*
- Tubifex tubifex
- Tubificidae w/o hair setae

Class Hirudinea
- Haemopsis kingi*
- Illinobdella moorei*

Phylum Arthropoda

Class Arachnoidea
- Neumania sp.*

Class Crustacea
- Hyalella azteca
- Lirceus fontinalis

Class Insecta

Order Diptera
- Ablabesmyia sp.*
- A. mallochi
- A. ornata
- A. parajanta
- Bezzia sp. 1

Order Diptera (continued)
- Bezzia sp. 2
- Chaoborus punctipennis
- Chironomidae sp.*
- Chironomus sp.
- C. decorus gr.
- C. plumosus gr.
- Cladotanytarsus sp.
- Corynoneura fittkaui*
- Cricotopus bicinctus*
- C. tremulus
- C. sylvestris*
- Cryptochironomus fulvus
- Endochironomus nigricans
- Eukiefferiella sp.*
- E. discoloripes*
- Glyptotendipes sp.
- G. barbipes*
- G. lobiferus
- Labrundinia pilosella*
- Limnochironomus sp.*
- L. leucoscelis
- L. neomodestus
- L. nervosus*
- Microchironomus sp.*
- Micropsectra sp.
- Nanocladius sp.*
- N. crassicornis*
- N. minimus*
- N. rectinervis
- Nilodorum sp.
- Nilothauma babiyi
- Orthocladius sp.
- O. curtiseta*
- O. obumbratum
- Orthocladius-Cricotopus gr. sp. 1
- Parachironomus carinatus
- P. hirtulatus π
- Parakiefferiella coronata*
- Paratanytarsus sp.
- Phaenopsectra dyari*
- P. flavipes*
- P. vittataπ
- Polypedilum sp.*
- P. flavipes*
- P. halterale
- P. illinoense*

TABLE D-7
(continued)
DRIFT MACROINVERTEBRATE TAXONOMIC LIST
CLARKS HILL LAKE
1981

Class Insecta
 Order Diptera
  Polypedilum scalaenum
  *Potthastia longimanus**
  Procladius bellus
  Procladius sp. 3
  Psectrocladius sp.*
  P. psilopterus
  Pseudochironomus sp. 1*
  Pseudochironomus sp. 2*
  Rheotanytarsus sp. *
  *Stenochironomus hilaris**
  Tanytarsus sp.
  T. glabrescens gr.*
  unknown genus No. 1*
  unknown genus No. 2*
 Order Trichoptera
  *Cyrnellus fraternus**
  Hydropsychidae sp.
  Ochrotrichia sp.
  Oecetis inconspicua
  Orthotrichia americana
  Oxyethira sp.
  Polycentropus sp.
  *Potamyia flava**
 Order Ephemeroptera
  Caenis sp.*
  Caenis diminuta
  *Ephemerella temporalis**
  Hexagenia munda
  Leptophlebia sp.*
 Order Odonata
  Anomalagrion sp.*
  *Argia moesta**
  Epicordulia regina
 Order Megaloptera
  Sialis sp.

Phylum Mollusca
 Class Gastropoda
  Amnicola sp.*
  A. limosa
  Physa sp.*
  *P. heterostropha**
  P. integra
  Valvata tricarinata simplex
 Class Pelecypoda
  Corbicula fluminea
  immature Sphaeriidae

*Taxa not found in the benthic macroinvertebrate collection.

No asterisk means that the taxon was found in both benthic and drift macroinvertebrate collections.

CHI
TABLED-7A

TABLE D-8

SUMMARY OF DRIFT MACROINVERTEBRATE COLLECTION DATA
CLARKS HILL LAKE
1981

	Density (no./m^2)								
	March			July			October		
Station	Shallow[a]	Mid	Deep[b]	Shallow[a]	Mid	Deep[b]	Shallow[a]	Mid	Deep[b]
1	0	0	0	45	177	31	3	15	9
3	648	174	58	158	143	131	111	48	61
5	372	27	3	773	391	36	43	159	49
7	1235	270	119	969	1082	15	79	227	98
9	308	75	49	85	187	1063	245	254	136
11	-[c]	6	-[c]	144	518	230	15	119	465
	Biomass (g/m^2)								
1	0.000	0.000	0.000	0.012	0.135	0.018	0.001	0.003	0.003
3	1.722	1.418	0.058	0.449	0.043	0.049	0.003	0.062	0.046
5	0.427	0.022	0.003	0.043	0.062	0.015	0.077	0.022	0.006
7	1.556	0.077	0.043	0.271	0.431	0.001	0.006	0.012	0.055
9	0.092	0.018	0.009	0.271	0.172	0.295	0.043	0.175	0.018
11	-[c]	0.074	-[c]	0.065	0.492	0.117	0.022	0.145	0.313

TABLE D-8
(continued)
SUMMARY OF DRIFT MACROINVERTEBRATE COLLECTION DATA
CLARKS HILL LAKE
1981

Station	Diversity ($no./m^2$)								
	March			July			October		
	Shallow[a]	Mid	Deep[b]	Shallow[a]	Mid	Deep[b]	Shallow[a]	Mid	Deep[b]
1	0.00	0.00	0.00	2.47	2.20	1.33	0.00	1.37	1.59
3	3.36	3.59	2.16	3.18	3.30	3.22	2.22	2.41	2.27
5	2.93	1.67	0.00	2.72	2.91	1.33	1.73	2.66	1.05
7	2.36	1.89	1.79	2.55	2.35	1.92	1.69	0.14	1.43
9	3.62	3.27	1.97	2.27	2.37	2.51	2.36	1.49	2.08
11	-[c]	1.00	-[c]	2.61	3.68	2.85	0.00	2.35	1.22

[a]At Station 11, the data are for the East station.

[b]At Station 11, the data are for the West station.

[c]No samplers recovered.

CHI
TABLED-8

TABLE D-9

DRIFT MACROINVERTEBRATE COMMUNITY STRUCTURE BY
PERCENTAGE COMPOSITION OF MAJOR TAXONOMIC GROUPS
CLARKS HILL LAKE
1981

		Percentage composition						
Station	Month	Molluscs	Crustaceans	Annelids	Miscellaneous	Chironomid insects	Non-chironomid[a] insects	Total specimens
1	March	0.0	0.0	0.0	0.0	0.0	0.0	0
	July	71.5	0.0	0.0	1.2	17.8	9.5	82
	October	0.0	0.0	22.2	11.1	22.2	44.5	9
3	March	0.0	0.0	4.4	0.3	93.6	1.7	286
	July	4.9	0.7	25.6	0.0	54.8	14.0	140
	October	4.1	0.0	2.7	0.0	87.7	5.5	72
5	March	0.0	6.2	37.6	0.0	49.5	6.7	131
	July	0.5	0.0	39.0	0.5	51.6	8.4	390
	October	12.4	3.6	13.5	0.0	59.7	10.8	82
7	March	0.0	0.4	54.4	0.2	44.6	0.4	528
	July	0.0	0.0	2.5	0.1	93.6	3.8	672
	October	1.5	0.0	5.2	0.0	91.8	1.5	131
9	March	0.0	0.0	11.8	0.0	85.4	2.8	140
	July	0.2	0.0	14.5	0.2	79.9	5.2	434
	October	2.4	0.0	0.5	0.0	96.6	0.5	207
11	March	0.0	0.0	0.0	50.0	50.0	0.0	2
	July	29.9	3.4	18.3	5.2	42.5	0.7	290
	October	85.5	4.5	1.5	0.0	5.0	3.5	195

TABLE D-9
(continued)
DRIFT MACROINVERTEBRATE COMMUNITY STRUCTURE BY
PERCENTAGE COMPOSITION OF MAJOR TAXONOMIC GROUPS
CLARKS HILL LAKE
1981

		Percentage composition						
Station	Month	Molluscs	Crustaceans	Annelids	Miscellaneous	Chironomid insects	Non-chironomid[a] insects	Total specimens
All stations combined	March	0.0	0.9	33.6	0.3	63.4	1.8	1087
	July	7.7	0.5	16.0	1.0	69.3	5.5	2008
	October	26.8	1.7	3.7	0.1	63.9	3.8	695
1981	All months combined	9.0	0.9	18.8	0.6	66.6	4.1	[illegible]

[a]Includes *Bezzia* spp. and *Chaoborus punctipennis*.

CHI
TABLED-9

TABLE D-10

COMPARISON OF THE TEN NUMERICALLY DOMINANT DRIFT SPECIES
IN EACH SAMPLING PERIOD
CLARKS HILL LAKE
1981

	March		July		October		Total	
Rank	Taxon	Number of specimens	Taxon	Number of specimens	Taxon	Number of specimens	1981	Number of specimens
1	Limnochironomus neomodestus (F)[a]	197	Limnochironomus neomodestus (F)	414	Valvata t. simplex (S)	144	Limnochironomus neomodestus (F)	649
2	Nais pardalis (W)	187	Glyptotendipes lobiferus (F)	355	Glyptotendipes lobiferus (F)	93	Glyptotendipes lobiferus (F)	446
3	Nais variabilis (W)	156	Polypedilum scalaenum (F)	100	Chironomus plumosus (F)	65	Nais variabilis (W)	190
4	Glyptotendipes barbipes (F)	96	Immature Tubificidae (W)	98	Limnochironomus neomodestus (F)	38	Nais pardalis (W)	187
5	Tanytarsus sp. (F)	70	Limnochironomus nervosus (F)	84	Tanytarsus sp. (F)	20	Tanytarsus sp. (F)	168
6	Glyptotendipes sp. (F)	68	Physa sp. (S)	83	Corbicula fluminea (C)	20	Valvata simplex (S)	144
7	Paraklefflella sp. (F)	45	Tanytarsus sp. (F)	78	Nilodorum sp. (F)	19	Chironomus plumosus (F)	124
8	Limnochironomus sp. (F)	38	Dero abranchiata (W)	74	Endochironomus nigricans (F)	18	Immature Tubificidae (W)	105
9	Endochironomus nigricans (F)	26	Cyrnellus fraternus (T)	70	Nais sp. (W)	13	Polypedilum scalaenum (F)	100
10	Ablabesmyia parajanta (F)	24	Ablabesmyia mallochi (F)	62	Hyalella azteca (A)	12	Glyptotendipes barbipes (F)	96

[a] (F) = fly larva or pupa; (W) = worms; (C) = clam; (S) = snail; (T) = caddis fly larva; (A) = amphipod.

CHI
TABLED-10

TABLE D-11

COMPARISON OF THE TEN MOST WIDELY DISTRIBUTED[a] DRIFT SPECIES
IN EACH SAMPLING PERIOD
CLARKS HILL LAKE
1981

	March		July		October		Total	
Rank	Taxon	Number of samples	Taxon	Number of samples	Taxon	Number of samples	1981	Number of samples
1	Limnochironomus neomodestus (F)	9	Limnochironomus neomodestus (F)	11	Glyptotendipes lobiferus (F)	12	Limnochironomus neomodestus (F)	30
2	Glyptotendipes barbipes (F)	8	Ablabesmyia mallochi (F)	10	Limnochironomus neomodestus (F)	10	Glyptotendipes lobiferus (F)	21
3	Nais variabilis (W)	8	Chironomus plumosus (F)	10	Corbicula fluminea (C)	7	Chironomus plumosus (F)	15
4	Nais pardalis (W)	6	Glyptotendipes lobiferus (F)	9	Chironomus plumosus (F)	5	Ablabesmyia mallochi (F)	14
5	Tanytarsus sp. (F)	6	Dero abranchiata (W)	9	Immature Tubificidae (W)	5	Nais variabilis (W)	12
6	Limnochironomus leucoscelis (F)	6	Cyrnellus fraternus (T)	9	Endochironomus nigricans (F)	4	Corbicula fluminea (C)	11
7	Parakiefflella sp. (F)	4	Tanytarsus sp. (F)	8	Hyalella azteca (A)	4	Cyrnellus fraternus (T)	11
8	Limnochironomus sp. (F)	4	Limnochironomus nervosus (F)	8	Ablabesmyia mallochi (F)	4	Limnochironomus nervosus (F)	10
9	Nanocladius sp. (F)	4	Ablabesmyia parajanta (F)	8	Nilodorum sp. (F)	3	Hyalella azteca (A)	10
10	Ablabesmyia ornata (F)	4	Polypedilum scalaenum (F)	7	Nais sp. (W)	3	Immature Tubificidae (W)	10

[a]The most widely distributed organism was determined by the number of locations at which the organism was found. Organisms could occur at a maximum of 18 locations in each sampling period and at a maximum annual total of 54 locations.

[b](F) = fly larva or pupa; (W) = worm; (C) = clam; (T) = caddis fly larva; (A) = amphipod.

CHI
TABLED-11

TABLE D-12

LIFE HISTORY INFORMATION FOR THE MAJOR CHIRONOMID TAXA
CLARKS HILL LAKE
1981

Species	Habitat	Habit	Organic pollution tolerance	Ecological notes[a]
Limnochironomus neomodestus	Lentic-littoral	Burrower	Tolerant	Frequently associated with Limnochironomus nervosus and Glyptotendipes lobiferus. Very common and widely distributed in the U.S.
Limnochironomus nervosus	Lentic-littoral	Burrower	Tolerant	Occurs in situations of high chloride, high BOD, and low dissolved oxygen. Frequently associated with Glyptotendipes lobiferus, Limnochironomus neomodestus and various naidid worms.
Glytotendipes lobiferus	Lentic-littoral or profundal; lotic	Burrower	Tolerant	Often dominant in sewage-polluted areas. Frequently associated with Limnochironomus neomodestus, L. nervosus, and Nais communis.
Endochironomus nigricans	Lentic-littoral or profundal	Clinger (tube builder)	Tolerant	Often associated with Glyptotendipes lobiferus and Limnochironomus neomodestus in areas with high organic and nutrient levels. Occurs in areas of high alkalinity, chloride and sulfate.
Chironomus plumosus	Lentic-littoral or profundal; lotic	Burrower (tube builder)	Tolerant	Ecologically versatile and found in extremely polluted to clean waters. Usually present in communities dominated by Glyptotendipes lobiferus.
Ablabesmyia parajanta	Lentic-littoral; lotic	Sprawler (predator)	Facultative	Often collected with A. mallochi. Found in organically enriched, sluggish waters or clean, swiftly flowing waters.
Ablabesmyia mallochi	Lentic-littoral; lotic	Sprawler (predator)	Facultative	Often collected with A. parajanta. Probably has similar environmental requirements.
Polypedilum scalaenum	Lentic	Climber or clinger	Tolerant to facultative	May be collected with P. illinoense in areas of pH less than 4.5 and iron greater than 5.0 ppm.
Tanytarsus sp.	Lentic-littoral or profundal; lotic	Climber or clinger	Facultative	Tolerant of high pH (>8.5), high alkalinity (>210 ppm) and low dissolved oxygen (<4 ppm). Tends to occur more in rivers than in lakes.

TABLE D-12
(continued)
LIFE HISTORY INFORMATION FOR THE MAJOR CHIRONOMID TAXA
CLARKS HILL LAKE
1981

Species	Habitat	Habit	Organic pollution tolerance	Ecological notes[a]
Procladius sublettei	Lentic-profundal; lotic	Sprawler	Facultative	Considered a poor indicator species because it may occur in pristine or heavily polluted areas. Tends to burrow in sediment settling on multi-plate samplers.
Nanocladius spp.	Lotic or lentic-littoral	Sprawler	Tolerant to facultative	Commonly found in moderately oligotrophic to mesotrophic lakes and reservoirs. Generally rheophilic and saprophobic.

[a]Data from Simpson and Bode (1980), Merritt and Cummins (1978), Beck (1977), Roback (1974), Mason (1971).

CHI
TABLE D-12

E. PHYTOPLANKTON

INTRODUCTION

Phytoplankton consists of the chlorophyll-bearing algae that drift passively or have limited means of locomotion. They are, therefore, generally carried by waves and currents in aquatic environments. Phytoplankters are primary producers that use solar energy to convert inorganic nutrients into protoplasm by means of photosynthesis. Phytoplankters are consumed by zooplankters and other filter feeders. Therefore, phytoplankton abundance and composition affect many primary and higher level consumers such as zooplankton and fish.

Reservoirs and lakes typically support large mixed groups of plants and animals. Physical and chemical factors that influence phytoplankton standing crop and productivity include water temperature, light, nutrient availability and water currents. Phytoplankters vary in their response to changes in these parameters. The interaction among these parameters typically produces an evident seasonal cycle in the plankton population of lakes and reservoirs. Diatoms generally increase in late winter and early spring, green algae typically become abundant in early summer and blue-greens become abundant in late summer and fall (Palmer, 1977). Because phytoplankton groups differ in their relative food value, extensive changes in phytoplankton composition may alter or disrupt food chain relationships and affect the diversity and condition of consumer forms.

The objectives of the phytoplankton study at Clarks Hill Lake were to 1) obtain an adequate data base for establishing baseline conditions for future studies and 2) identify water quality and/or environmental problems to provide guidance in future lake management. These objectives were met by ascertaining phytoplankton composition, density and chlorophyll-*a* concentration within the lake, assessing seasonal and interstation variation, and relating findings to phytoplankton studies in other southeastern lakes.

MATERIALS AND METHODS

Phytoplankton and chlorophyll-*a* samples were collected at Stations 1 through 8 (Figure A-1; Table A-2) in February, April, June, August and October 1981 (Table A-3). Duplicate depth-integrated composite samples for both parameters were collected by taking grab samples with a Kemmerer water bottle. Duplicate 1-liter grab samples were taken at the surface and at 1-m intervals throughout the euphotic zone (to the depth of 1 percent light transmittance) and composited separately. One-liter aliquots of each depth-integrated composite sample were taken for phytoplankton analysis and immediately preserved in 4- to 5-percent buffered formalin. One- to two-liter aliquots for chlorophyll-*a* analysis were taken and immediately stored on ice in light-proof containers. Chlorophyll-a samples were filtered through Whatman GFC filters on the day of collection; these were folded in half with the filtered particulates on the inside, immediately frozen under darkened conditions and shipped in light-proof containers to the laboratory for extraction and analysis.

In the laboratory, phytoplankton samples were allowed to settle for a minimum of 4 hours per centimeter of sample depth before concentration (EPA, 1973). Microscopic analysis was performed by the Utermohl (1958) technique using inverted compound microscopes equipped with calibrated ocular micrometers. After subsamples had settled a minimum of 4 hours in settling chambers, phytoplankters were enumerated in random fields (Littleford et al., 1940; EPA, 1973; APHA, 1975). A minimum of 200 phytoplankters or 100 random fields was counted.

All phytoplankters, except some green and blue-green algae, were counted individually. Filamentous green and blue-green algae were measured in 100-μ standard lengths, with each length representing one counting unit. Colonial forms exclusive of diatoms were counted, with each colony representing one counting unit. An average number of individuals per colony was specified where possible. Cells per liter (N) were calculated by

$$N = \frac{\frac{V_s}{V_c} C}{V_i}$$

where: V_s = Volume of sample concentrate, in milliliters;

V_c = Counted concentrate volume; determined by multiplying the aliquot volume, in milliliters, by the proportion of the counting chamber that was examined;

C = Units counted; and

V_i = Initial sample volume, in liters.

Permanent diatom mounts were prepared and examined to verify the diatom species identifications from water mounts. References used in the identification of phytoplankton species were: Van Heurck (1896), Walton (1915), Hustedt (1930a, 1930b, 1959, 1961-1966), Rabenhorst (1933, 1937), Smith (1950), Whitford and Schumacher (1961), Prescott (1962), Patrick and Reimer (1966, 1975), Drouet (1968), Taft and Taft (1971), Weber (1971), Komarek (1974) and Prescott et al. (1975). Representative diatom mounts and vouchers of all samples analyzed were retained as a reference. Replicate and average phytoplankton density data were reported as number per liter by species (Appendix Tables E-1 through E-10).

Chlorophyll-a analyses were performed according to APHA (1975). Filters from replicate samples were extracted by grinding in a 90-percent aqueous solution of acetone. The volume of the extract was measured and extinction values were read with a spectrophotometer at a slit width of 1.0 nanometer (nm) using 1-cm cuvettes. Corrected chlorophyll-a and phaeophytin concentrations were determined from readings at 663 nm before and after the addition of 50-percent HCl. All extinctions were corrected by subtracting the turbidity reading at 750 nm. Replicate and average pigment concentrations were expressed as milligrams per cubic meter (Appendix Tables E-11 through E-15).

For statistical analysis, phytoplankton and pigment data were transformed to $\log_e$ to reduce the effect of non-homogeneous variation and skewness. The Statistical Analysis System (SAS; Barr et al., 1976) was used for all analyses. Variation among stations was examined by the General Linear Models (GLM) procedure, which provides the regression approach to analysis of variance.

RESULTS AND DISCUSSION

The phytoplankton community in Clarks Hill Lake was diverse during the study; 209 taxa in 7 divisions were identified (Table E-1). In terms of relative abundance and species richness, the most important phytoplankton groups were:

Group	Range of relative abundance	Number of species
Chlorophyta (greens)	9-64 percent	90
Bacillariophyta (diatoms)	7-59 percent	61
Cyanophyta (blue-greens)	<5-63 percent	29
Cryptophyta (cryptophytes)	<5-62 percent	3

The relative abundance of greens and blue-greens was greatest during warmwater periods (June, August and October), and diatom relative abundance was greatest during cool-water periods (February and April, Figure E-1). This seasonal variation in composition is typical of temperate freshwater phytoplankton communities and was similar to seasonal composition patterns observed in Lake Sidney Lanier, Georgia (USACOE, 1981). Phytoplankton within the lake was somewhat more diverse during February and October when the water column was well-mixed. Under stratified conditions, the phytoplankton consisted predominantly of diatoms, greens and cryptophytes in April and of diatoms, greens and blue-greens in June and August. Variation in community composition among stations did not show consistent differences in community structure within the lake.

Thirty-six phytoplankton taxa were considered to be major taxa (comprising 5 percent or more of the total phytoplankton density at one or more stations on at least one occasion during the study; Table E-2). *Melosira distans* is characteristic of water with low nutrient concentrations that may be rich in humic material (Lowe, 1974). This diatom was most frequently in major abundance at Station 1, an area of the lake classified as meso-eutrophic in 1973 (EPA, 1976a). *Cyclotella stelligera*, *C. pseudostelligera*, *Melosira distans*, *M. granulata*, *M. granulata* v. *angustissima*, *Nitzschia acicularis* and *Tabellaria fenestrata* are diatoms characteristic of eutrophic waters. *C. stelligera* was the most frequently dominant diatom and occurred as a major species throughout the lake in June, when it comprised 12 to 22 percent of the phytoplankton.

Major diatom taxa were most frequently observed in February and April, and major green and blue-green taxa occurred most frequently from June through October (Table E-2). *Ankistrodesmus falcatus* and *Chlorella* are green algae associated with organically enriched waters (Palmer, 1977). Blue-greens in general occur particularly in mesotrophic to eutrophic freshwater habitats (Carr and Whitton, 1973). *Ankistrodesmus falcatus* occurred as a major phytoplankter in February, August and October. This species was most frequently observed in the Broad River and the Georgia and South Carolina Little Rivers during the fall, when it comprised 6 to 28 percent of the total phytoplankton. The blue-green *Chroococcus dispersus* and coccoid greens were major taxa throughout the lake in June and coccoid greens were major taxa in October as well. The distribution of major phytoplankton taxa within the lake did not present clear trends that indicated consistent localized habitat differences. Several of these major phytoplankters, particularly *Cyclotella*, *Melosira* and *Ankistrodesmus* species, have been reported as dominant in Lake Sidney Lanier (ESE, 1981).

Total phytoplankton density ranged from 0.9 x 10^6 cells per liter at Stations 6 and 2 in February and April, respectively, to 11.4 x 10^6 cells per liter at Station 8 in August (Tables E-3 through E-7). The maximum and minimum density levels were similar in magnitude to those reported for Lake Seminole, Florida, Lake Fontana, North Carolina, Lake Sidney Lanier, Georgia, and other lakes in the southeast (Morris et al., 1978; U.S. Army Corps of Engineers, 1980; ESE, 1981). The range in density during the present study was similar to that observed in Clarks Hill Lake in 1973 (EPA, 1976a). Overall, densities in Clarks Hill Lake during 1981 were slightly higher than those reported for Lake Sidney Lanier where densities ranged from approximately 0.2 x 10^6 to 4.6 x 10^6 cells per liter when excluding two tributary stations that receive effluent from a sewage treatment facility.

Variation in density among seasons was greater than variation among stations. Phytoplankton density was typically lowest in April and highest in June, although seasonal variation was not consistent among stations (Figure E-2). The inconsistent seasonal variation among stations resulted in a statistically significant station x month interaction (Table E-8). Overall, phytoplankton density was significantly higher in June and August than in other months and significantly lower in April than in all other months. Phytoplankton densities in the Georgia and South Carolina Little Rivers (Stations 5 and 7), in the Broad River (Station 8), and in the upper lake (Stations 3 and 4) were significantly greater than those near the dam (Stations 1, 2 and 6; Figure A-1; Table E-8).

Corrected chlorophyll-a in Clarks Hill Lake ranged from 1.27 to 12.69 mg/m^3 as compared to a range of 0.90 to 3.26 mg/m^3 reported for Lake Sidney Lanier, Georgia, which has been given a lake-wide classification of oligo-mesatrophic (Table E-9; ESE, 1981). Chlorophyll-a increased within the lake from February to October (Figure E-3). As observed for phytoplankton density, chlorophyll-a was significantly greater at Stations 5, 7, 8 and greater in the upper lake in general than at Stations 1 and 6 near the dam (Table E-10). Seasonal and areal maxima for chlorophyll-a did not directly correspond to those for phytoplankton density because of differences in community composition among seasons and stations. However, both of these independent measures of standing crop reflected a seasonal pattern of increasing productivity from early spring through fall and showed that standing crop was highest in the Georgia and South Carolina Little Rivers and the Broad River and lowest near the dam.

Phaeopigment is a stable degradation product of chlorophyll-a and accumulates in the sediments of lakes and reservoirs. As expected, phaeopigment concentrations were highest in February following the winter period of decreased production and increased mixing within the lake (Table E-11). Differences in phaeopigment concentration among stations appeared to be most directly related to water depth. Concentrations were higher at shallower stations (3, 4, 5 and 8) than at deeper stations (1, 2 and 7). This finding may reflect the influence of sampling methodology, because phaeopigment concentration would be expected to increase with depth. Samples from the euphotic zone at the shallower stations represented a proportionately greater amount of the water column and were taken closer to the bottom than those from deeper stations.

Phytoplankton standing crop progressively decreased from the Broad River (Station 8) to the dam (Station 1). This same trend was observed from the Georgia and South Carolina Little Rivers (Stations 5 and 7) to the dam (Figure E-4). These tributaries, as well as the upper lake above Stations 3 and 4, were considered eutrophic in 1973, and the mid-reservoir (Stations 2, 3 and 4) was considered to be meso-eutrophic (EPA, 1976a). Eutrophication may be broadly defined as nutrient or organic matter enrichment (Likens, 1972). All lakes undergo eutrophication as a natural aging process. This natural aging process may be greatly accelerated by man's activities. When enrichment of the aquatic ecosystem results in undesirable water quality, eutrophication is often considered a form of pollution, although pollution and eutrophication are not synonymous terms.

The distribution in phytoplankton standing crop during the present study corresponded to the distribution of total phosphate within the lake (Figure B-2) and reflected the continued influence of phosphate input via tributaries. Average phosphates at stations other than 1 and 2, exceeded EPA recommended limits for phosphate concentration (EPA, 1976b). Corrected chlorophyll-*a* concentrations in the Georgia Little River presently exceed the uncorrected concentration observed in 1973, even though the earlier, uncorrected measurements would over-estimate chlorophyll-*a*. The major phytoplankton taxa found within the lake were similar to those observed in several eutrophic lakes in North Carolina (Morris et al., 1978). Notable similarities were the occurrences of *Melosira* and *Cyclotella* species, cryptophytes and other flagellates with late summer to fall prevalence of *Raphidiopsis*. The data indicate continued nutrient enrichment within the lake since 1973, a consequence of natural aging processes. At present, concentrations of utilizable inoganic phosphate and nitrate in the lake area generally below the critical levels (0.15 and 0.3 mg/m^3, respectively) above which phytoplankton blooms may occur (Allen and Kramer, 1972). Widespread algal blooms resulting in undesirable water quality are unlikely at present.

SUMMARY

The most important phytoplankton groups in Clarks Hill Lake were green algae, diatoms and blue-green algae. The greens and blue-greens were relatively more important during warmwater periods, and diatom relative abundance was greatest during cooler water periods. Phytoplankters were somewhat more diverse when the water column was well-mixed. Many of the major phytoplankton taxa observed during the study (*Cyclotella* and *Melosira* species, *Nitzschia acicularis*, *Tabellaria fenestrata* and *Ankistrodesmus falcatus*) were characteristic of eutrophic habitats. However, variation in community composition did not show consistent localized habitat differences within the lake.

Total phytoplankton density ranged from 0.9 x 10^6 to 11.4 x 10^6 cells per liter. These density levels were similar to those reported for other lakes in the southeast, including Lake Seminole, Florida, and Lake Fontana, North Carolina, and Lake Sidney Lanier, Georgia and were of similar magnitude to density levels in Clarks Hill Lake in 1973. The range in corrected chlorophyll-*a* concentration was 1.27 to 12.69 mg/m^3. Chlorophyll-*a* concentration during the present study exceeded chlorophyll-*a* levels measured in the Georgia Little River during 1973. There was a seasonal pattern of increasing productivity from early spring through fall. Standing crop was highest in the Georgia and South

The progressive decrease in standing crop from these tributaries to the dam corresponded to the distribution of total phosphate within the lake and reflected the continued influence of phosphate input to the lake. Corrected chlorophyll-a concentration and distribution and the occurrence of major phytoplankton taxa that are similar to those observed in several eutrophic lakes in the southeast indicated continued nutrient enrichment within the lake since 1973. However, present nutrient concentrations are below critical values at which algal blooms can occur and widespread blooms resulting in undesirable water quality are unlikely.

LITERATURE CITED

Allen, H.E. and J.R. Kramer. 1972. Nutrients in natural waters. John Wiley & Sons, New York. 457 pp.

APHA. 1975. Standard methods for the examination of water and wastewater, 14th ed. American Public Health Assoc., Washington, D.C. 1193 pp.

Barr, J.A., J.G. Goodnight, J.P. Sall, and J.T. Helwig. 1976. The user's guide to SAS 76. Sparks Press of Raleigh, NC. 329 pp.

Carr, N.G., and B.A. Whitton. 1973. The biology of blue-green algae. Univ. of California Press, Berkeley. 676 pp.

Drouet, F. 1968. Revision of the classificaton of the Oscillatoriaceae. The Academy of Natural Sciences of Philadelphia. Monograph 15. 370 p.

EPA (Environmental Protection Agency). 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. C.I. Weber, ed. EPA 670/4-73-001. U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, OH.

__________. 1976a. National eutrophication survey. Report on Clark's Hill Reservoir. Working paper series No. 287, EPA Region IV, U.S. Environmental Protection Agency.

__________. 1976b. Quality criteria for water. EPA-440/9-76-023. U.S. Environmental Protection Agency, Washington, D.C. 501 pp.

ESE (Environmental Science and Engineering, Inc.) 1981. Water Quality Management Study, Lake Sidney Lanier. Presented for U.S. Army Corps of Engineers, Mobile District. Vol. I-IV.

Hustedt, F. 1930a. Die susswasser-flora mitteleuropas. Verlag von Gustav Fischer, Deutschland. 466 pp.

__________. 1930b. Die Kieselalgen Deutschlands, Osterreicha und der Schweiz. Part 1, Otto Koeltz Science Publishers. Koenigstein, West Germany. 920 pp.

__________. 1959. Die susswasser-flora mitteleuropas. Part 2, Otto Koeltz Science Publishers. Koenigstein, West Germany. 920 pp.

__________. 1961-1966. Die suswasser-flora mitteleuropas. Part 3, Otto Koeltz Science Publishers. Koenigstein, West Germany. 815 pp.

LITERATURE CITED (continued)

Komarek, J. 1974. The morphology and taxonomy of Crucigenioid algae (Scenedesmuceae, Chlorococcales). Archiv. fur Pratistenkunde 116:1-75.

Likens, G.E. 1972. Eutrophication and aquatic ecosystems. Pages 3-13 in G.E. Likens ed. Nutrients and eutrophication. American Society of Limnology and Oceanography, Special Symposia Vol. 1. 328 pp.

Littleford, R.A., C.L. Newcombe, and B.B. Shepherd. 1940. An experimental study of certain quantitative plankton methods. Ecology 21(3):309-322.

Lowe, R.L. 1974. Environmental requirements and pollution tolerance of freshwater diatoms. U.S. Environmental Protection Agency, Cincinnati, Ohio. 333 pp.

Morris, M.K., L.R. Williams, W.D. Taylor, F.A. Hiatt, S.C. Hern, J.W. Hilgert, V.W. Lambou, and F.A. Morris. 1978. Distribution of phytoplankton in North Carolina lakes. EPA-600/3-78-051. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Las Vegas, Nevada. 73 pp.

Patrick, R., and C.W. Reimer. 1966. The diatoms of the United States, exclusive of Alaska and Hawaii, Vol. 1. Monographs of the Academy of Natural Sciences of Philadelphia. 688 pp.

______________________. 1975. The diatoms of the United States, exclusive of Alaska and Hawaii, Vol. 2, Part 1. Monographs of the Academy of Natural Sciences of Philadelphia. 213 pp.

Palmer, C.M. 1977. Algae and water pollution. Prepared for USEPA Municipal Environmental Research Lab., Cincinnati, Ohio, as EPA-600/9-77-036 by NTIS, Publ, No. P13-287-128. 123 pp.

Prescott, G.W. 1962. Algae of the Western Great Lakes Area. Wm. C. Brown Company, Dubuque, IA. 977 pp.

Prescott, G.W., H.T. Croasdale, and W.C. Vinyard. 1975. A synopsis of North American desmids, Part II, Desmidiaceae: Placodermae Section I. University of Nebraska Press, Lincoln, Nebraska. 275 pp.

Rabenhorst, L. 1933. Kryptogamen - Flora, Volume X, Section III, Part. 1. Strauss α Cramer GmbH. West Germany 617 pp.

______________. 1937. Kryptogamen - Flora, Volume X, Section III, Part. 2. Strauss α Cramer GmbH. West Germany 589 pp.

Smith, G.M. 1950. The fresh-water algae of the United States. McGraw Hill Book Company, NY. 719 pp.

LITERATURE CITED (continued)

Taft, C.E., and C.W. Taft. 1971. The algae of western Lake Erie. Bull. Ohio Biol. Survey. New Series 4(1):1-189.

U.S. Army Corps of Engineers. 1980. Water quality management studies, technical report ACF 80-1 (interim report). Lake Seminole. April-November 1978.

______________________________. 1981. Water quality management studies, technical report ACF 80-1 (interim report). Lake Seminole. April-November 1978.

Utermohl, H. 1958. Zur vervollkommnung der quantitativen phytoplankton methodek. Mitl. Intern. Ver. Oimnol. 9:1-38.

Van Heurck, H. 1896. A treatise on the Diatomaceae. Translated by W.E. Baxter, Ltd. London. 559 pp.

Walton, L.B. 1915. A review of the described species of the order Euglenoidina Bloch class Flagellata (protozoa) with particular reference to those found in the city water supplies and other localities of Ohio. Ohio Bilogical Survey Bulletin 4. The Ohio State University Bulletin Vol. XIX, No. 5. 116 pp.

Weber, C.I. 1971. A guide to the common diatoms at water pollution surveillance system stations. PB-230-249. U.S. Environmental Protection Agency. 101 pp.

Whitford, L.A., and G.J. Schumacher. 1961. Effect of current on mineral uptake and respiration by a freshwater alga. Limnol. Oceangr. 6, 423-5.

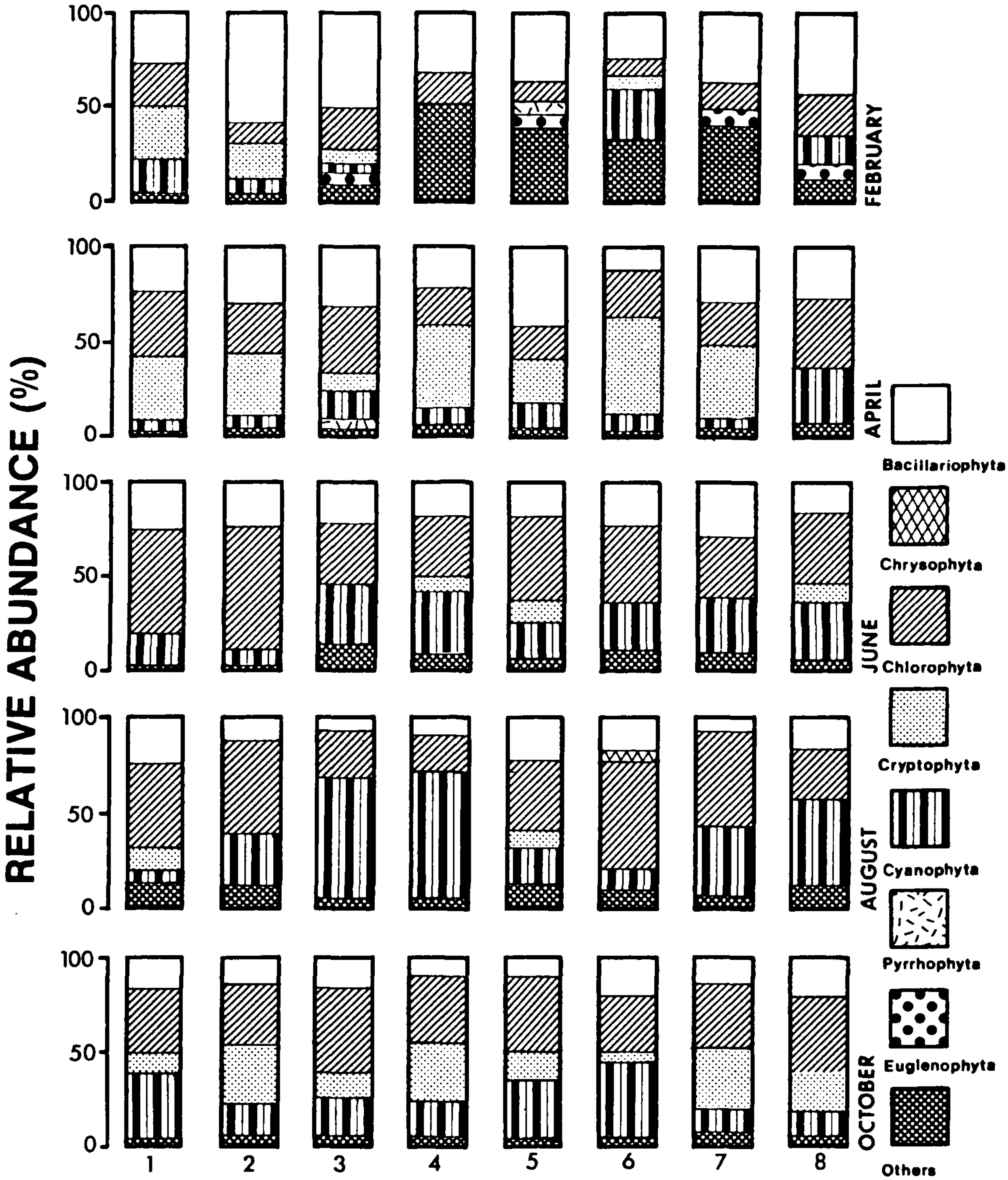


Figure E-1. Phytoplankton composition, Clarks Hill Lake, February-October 1981.

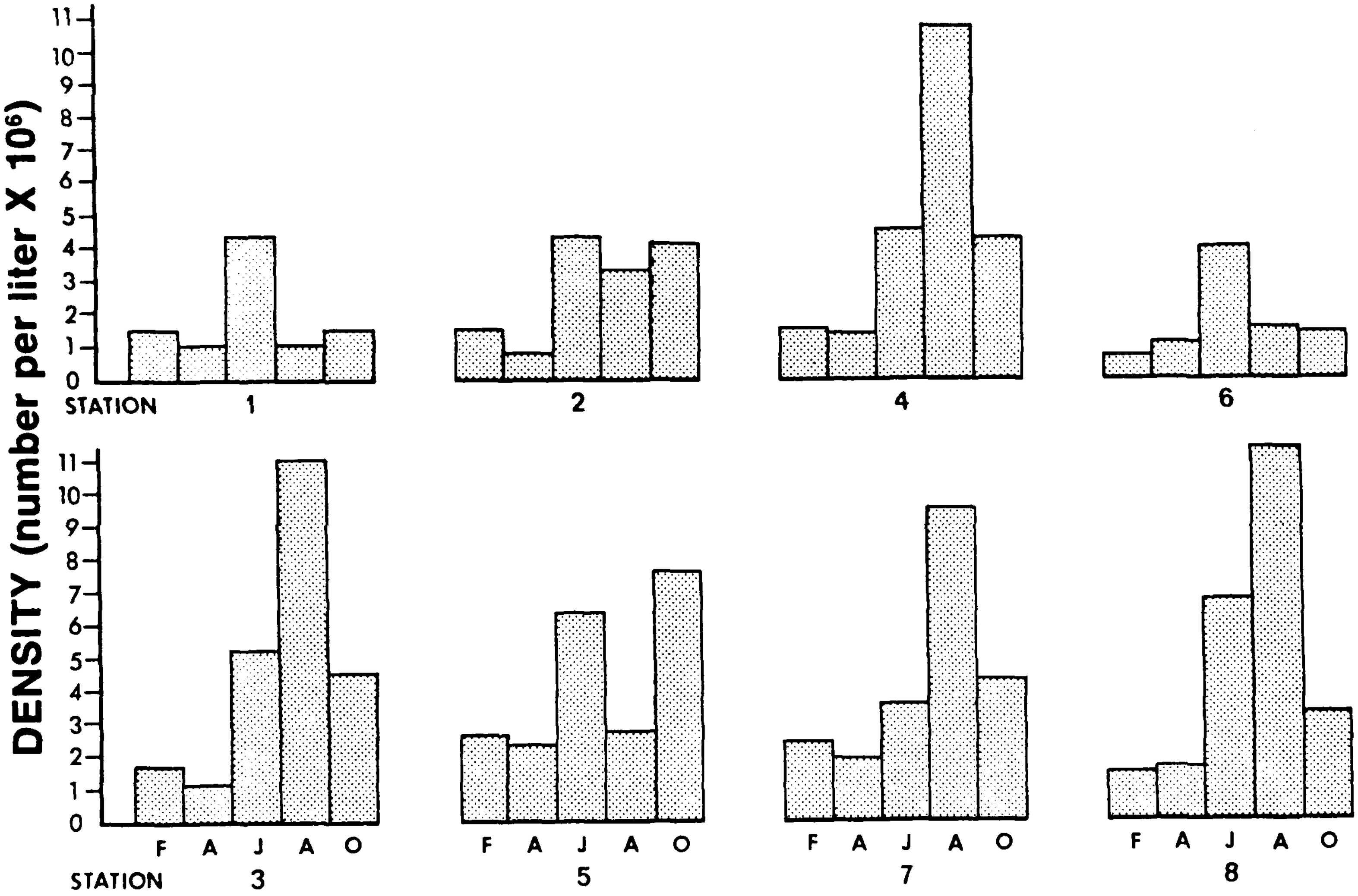


Figure E-2. Total phytoplankton density, Clarks Hill Lake, February, April, July, August and October.

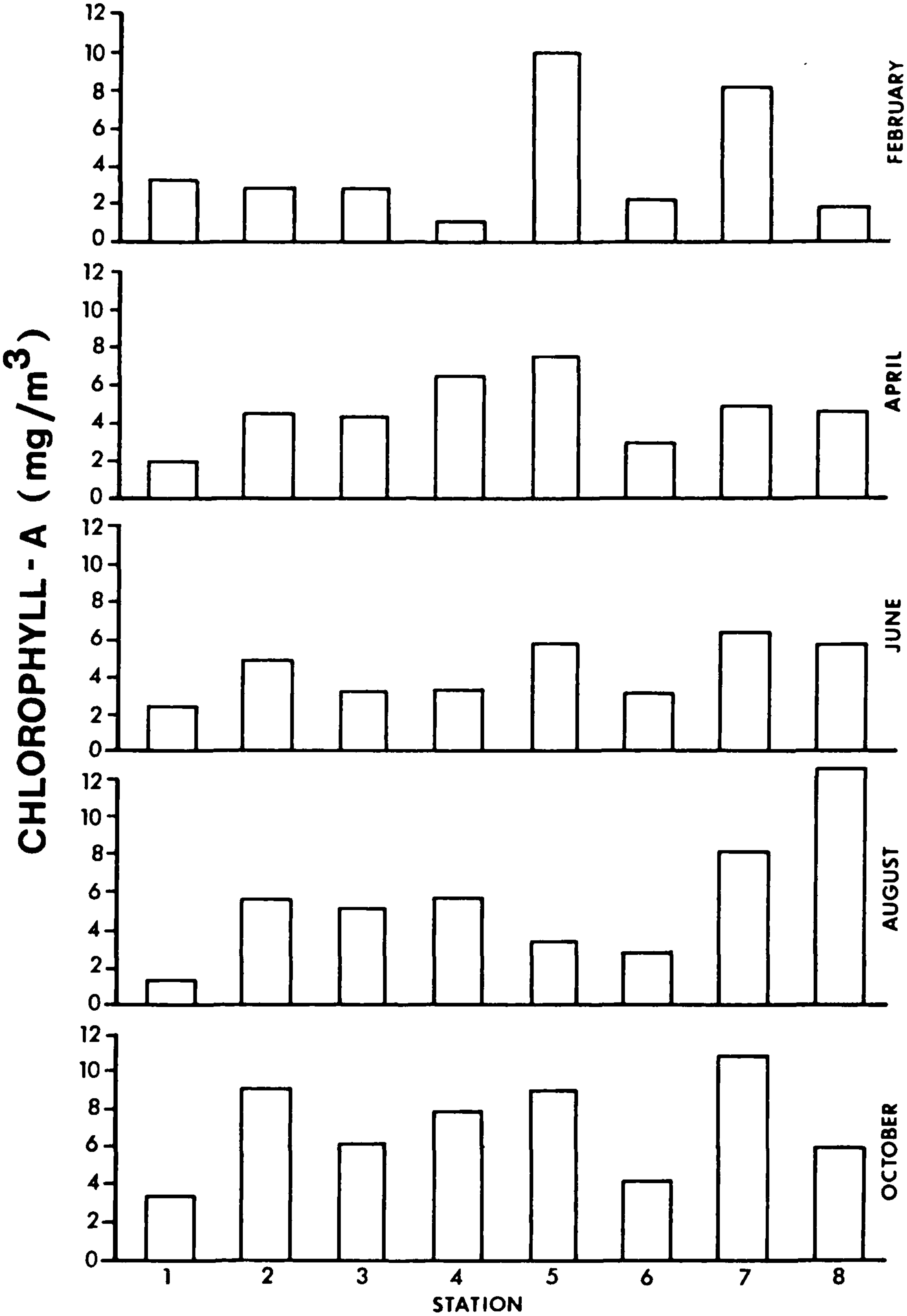


Figure E-3. Corrected chlorophyll-a, Clarks Hill Lake, February-October 1981.

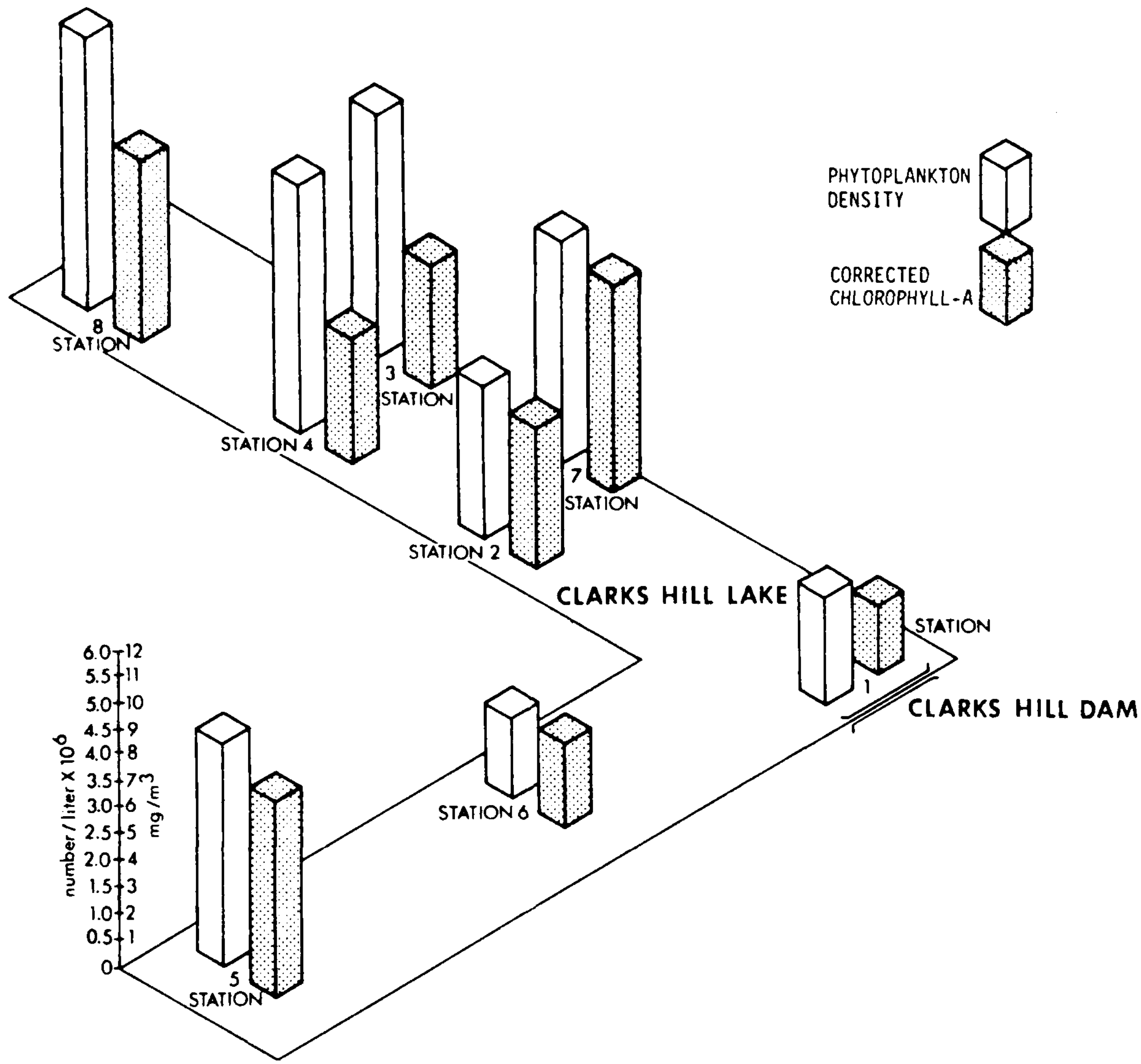


Figure E-4. Average phytoplankton density (no./liter) and chlorophyll-a (mg/m3), Clarks Hill Lake, February, April, June, August and October 1981.

TABLE E-1

PHYTOPLANKTON SPECIES
CLARKS HILL LAKE
FEBRUARY - OCTOBER 1981

BACILLARIOPHYTA
- Achnanthes exigua
- A. lanceolata
- A. lanceolata v. dubia
- A. linearis f. curta
- A. microcephala
- A. minutissima
- Achnanthes spp.
- Amphora coffeiformis
- Asterionella formosa
- A. formosa v. gracillima
- Cocconeis sp.
- Cyclotella glomerata
- C. Meneghiniana
- C. pseudostelligera
- C. stelligera
- Cyclotella sp.
- Cymbella lunata
- Cymbella sp.
- Eunotia arcus v. bidens
- Frustulia rhomboides v. saxonica
- Gomphonema acuminatum
- G. angustatum
- G. gracile
- Gomphonema sp.
- Melosira distans
- M. granulata
- M. granulata v. angustissima
- M. hertzogi
- M. islandica subspec. helvetica
- M. italica
- Navicula cryptocephala
- N. decussis
- N. hungarica
- N. notha
- N. pupula
- Navicula spp.
- Nitzschia acicularis
- N. gandersheimiensis
- N. holsatica
- N. hydrida
- N. palea
- N. sigmoidea
- Nitzschia sp.
- Pinnularia termitina
- Rhizosolenia eriensis

BACILLARIOPHYTA (continued)
- Rhizosolenia longiseta
- Rhizosolenia sp.
- Rhoicosphenia curvata
- Synedra filiformis
- S. filiformis v. exilis
- S. incisa
- S. parasitica
- S. rumpens
- S. ulna
- S. vaucheriae
- Synedra spp.
- Tabellaria fenestrata
- T. flocculosa
- centric diatom spp. $<20\mu$
- pennate diatom spp. $<20\mu$
- pennate diatom spp. $>20\mu$

CHRYSOPHYTA
- Arachnochloris ? sp.
- Dinobryon divergens
- D. sociale
- D. vanhoeffenii

CHLOROPHYTA
- Acanthosphaera zachariasi
- Ankistrodesmus convolutus
- A. falcatus
- A. falcatus v. acicularis
- A. falcatus v. mirabilis
- Carteria spp.
- Characium limneticum
- Characium ? sp.
- Chlamydomonas globosa
- Chlamydomonas spp.
- Chlorella sp.
- Chlorococcum spp.
- Chlorogonium sp.
- Closteriopsis longissima
- Closterium sp.
- Coelastrum sphaericum
- Coelastrum sp.
- Cosmarium subtumidum v. Klebsii
- Cosmarium spp.
- Crucigenia apiculata
- C. rectangularis

TABLE E-1
(continued)
PHYTOPLANKTON SPECIES
CLARKS HILL LAKE
FEBRUARY - OCTOBER 1981

CHLOROPHYTA (continued
- Crucigenia tetrapedia
- C. truncata
- Dictyosphaerium Ehrenbergianum
- D. pulchellum
- Elakatothrix gelatinosa
- Euastrum sp.
- Franceia droescheri
- F. ovalis
- Gloeocystis sp.
- Golenkinia radiata
- Kirchneriella contorta
- K. lunaris
- K. lunaris v. dianae
- K. lunaris v. irregularis
- K. obesa
- K. obesa v. major
- K. subsolitaria
- Lagerheimia quadriseta
- L. subsalsa
- Micractinium pusillum
- M. quadrisetum
- Nephrocytium limneticum
- Oocystis Borgei
- O. lacustris
- O. parva
- O. pusilla
- Oocystis spp.
- Pandorina morum
- Pediastrum duplex
- P. obtusum
- P. tetras v. tetraodon
- Pediastrum sp.
- Penium sp.
- Polyedriopsis quadrispina
- Quadrigula lacustris
- Scenedesmus abundans
- S. acuminatus
- S. acutiformis ?
- S. Bernardii
- S. bijuga
- S. denticulatus
- S. dimorphus
- S. incrassatulus
- S. quadricauda

CHLOROPHYTA (continued)
- Selenastrum minutum
- S. westii
- Sphaerocystis schroeteri
- Staurastrum chaetoceros
- S. curvatum
- S. curvatum v. elongatum
- S. dejectum
- S. paradoxum
- S. striolatum
- S. tetracerum
- Tetraedron caudatum
- T. minimum
- T. muticum
- T. regulare v. incus
- T. trigonum
- Tetrastrum glabrum
- T. heteracanthum
- T. punctatum
- Treubaria setigerum
- Volvox tertius
- Westella botryoides
- coccoid green spp.

CRYPTOPHYTA
- Cryptomonas ovata
- Cryptomonas spp.
- cryptophyte spp.

CYANOPHYTA
- Anabaena macrospira v. robusta
- A. spiroides v. crassa
- Anabaena spp.
- Anacystis spp.
- Aphanocapsa elachista
- Aphanothece clathrata
- Aphanothece sp.
- Chroococcus disperus
- C. limneticus
- Dactylococcopsis fascicularis
- D. rhaphidioides
- D. smithii
- Gomphosphaeria aponina
- G. lacustris
- G. lacustris v. compacta

TABLE E-1
(continued)
PHYTOPLANKTON SPECIES
CLARKS HILL LAKE
FEBRUARY - OCTOBER 1981

CYANOPHYTA (continued)
- *Merismopedia glauca*
- *M. tenuissima*
- *Microcystis incerta*
- *Microcystis* spp.
- *Oscillatoria* spp.
- *Raphidioposis curvata*
- *Raphidioposis* sp.
- *Rhabdoderma lineare*
- *Spirulina laxissima*
- *Synechococcus aeruginosus*
- *Synechocystis aquatilis*
- filamentous blue-green spp.

PYRRHOPHYTA
- *Ceratium hirundinella*
- *Cystodinium cornifax*
- *Glenodinium gymnodinium*
- *G. pulvisculus*
- *Glenodinium* spp.
- *Gymnodinium* spp.
- *Peridinium inconspicuum*

PYRRHOPHYTA (continued)
- *P. Wisconsinense*
- *Peridinium* spp.
- dinoflagellate spp.
- dinoflagellate cyst

EUGLENOPHYTA
- *Euglena gracilis*
- *Euglena* spp.
- *Phacus pseudowirenkoi*
- *Trachelomonas charkowiensis*
- *T. creba*
- *T. intermedia*
- *T. lacustris*
- *T. vermiculosa*
- *T. volvocina*
- *Trachelomonas* spp.
- euglenoid spp.

OTHERS
- phytoflagellate spp. $>10\mu$
- phytoflagellate spp. $<10\mu$

TABLE E-2

MAJOR PHYTOPLANKTON TAXA AND STATIONS WHERE THEY OCCURRED[a]
CLARKS HILL LAKE
FEBRUARY - OCTOBER 1981

Taxon	February	April	June	August	October
BACILLARIOPHYTA					
Asterionella formosa v. *gracillima*	7				
Cyclotella glomerata	3 7 8				
C. pseudostelligera	2 4 5				
C. stelligera	1 3 8	1 7	1 2 3 4 5 6 7 8	1 5 6 8	1 7
Melosira distans		1 6 7		1	1
M. granulata	1 2 5	3 5 8			
M. granulata v. *angustissima*		5			
M. islandica subsp. *helvetica*					6
Nitzschia acicularis	2 3 4 7 8				8
Synedra filiformis v. *exilis*	2 3 4 7				
Tabellaria fenestrata		2 3			
CHRYSOPHYTA					
Dinobryon divergens				6	
CHLOROPHYTA					
Ankistrodesmus convolutus	7				
A. falcatus	1 3 4 6	2		7 8	2 3 4 5 7 8
Chlorella sp.			4 5 6 7 8		1 2 3 4 6 8
Chlorococcum spp.			4 5 7		1
Cosmarium spp.			2		
Crucigenia tetrapedia		1			
Kirchneriella lunaris v. *Dianae*			5 6 8		
Oocystis parva		1			
Sphaerocystis Schroeteri		2 6 7 8			
Tetraedron caudatum				1	
T. minimum					6
coccoid green spp.	3		1 2 3 6 7 8	1 2 3 4 5 7 8	
CRYPTOPHYTA					
cryptophyte spp.	1 2 3 6	1 2 3 4 5 6 7	4 5 8	1 5	1 2 3 4 5 7 8
CYANOPHYTA					
Anacystis spp.	1 6 8				
Aphanothece clathrata			6		1
Chroococcus disperus		3 4 5 8	1 3 4 5 6 7 8	7	5 6
Dactylococcopsis Smithii		8			
Gomphosphaeria lacustris					1 6
Lyngbya sp.			7	3 5	
Merismopedia tenuissima			8		5
Microcystis incerta			2 3 4 7 8	3 4 5 6 7	1 2 3 4 6
Raphidiopsis sp.				2 3 4 7 8	
EUGLENOPHYTA					
Trachelomonas spp.	3 5 7 8				
OTHERS					
phytoflagellate spp. <10µ	3 4 5 6 7		3 4	1 5 6	

[a]Each species comprised 5 percent or more of the total phytoplankton density.

TABLE E-3

SUMMARY OF PHYTOPLANKTON DENSITY (no./liter)
CLARKS HILL LAKE
24 FEBRUARY 1981

	Station and replicate											
	1			2			4			6		
Taxon	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Bacillariophyta	446490	363986	405239	1067692	752239	909963	508013	508015	508018	319862	142149	231005
Chrysophyta	-	-	-	-	-	-	-	-	-	-	-	-
Chlorophyta	399980	242660	321319	194127	157728	175926	259651	248360	254010	100349	61804	81076
Cryptophyta	353471	485314	419392	315454	279056	297255	45157	33868	39512	106620	30902	68762
Cyanophyta	297659	251555	274606	145595	72798	109195	56446	79025	67735	260279	251545	255914
Pyrrhophyta	18604	8089	13346	12133	0	6066	0	22578	11289	6272	12361	9316
Euglenophyta	-	-	-	24266	48532	36399	67735	56446	62091	25087	0	12544
Others	18604	48531	33568	12133	12133	12133	620908	632197	626552	351220	191595	271408
Total	1,534,808	1,400,135	1,467,470	1,771,400	1,322,486	1,546,937	1,557,910	1,580,489	1,569,207	1,169,689	690,356	930,025

	Station and replicate											
	3			5			7			8		
Taxon	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Bacillariophyta	1007032	594512	800770	1314066	616877	965473	908948	908950	908949	564545	636613	600579
Chrysophyta	0	12133	6066	0	12096	6048	-	-	-	-	-	-
Chlorophyta	376120	315456	345784	189658	350773	270218	435795	261478	348642	348337	264256	306297
Cryptophyta	97063	109196	103129	40641	145148	92894	37354	24903	31128	24023	48046	36035
Cyanophyta	24266	134675	79470	94829	96764	95797	37353	3735	20546	204197	183779	193987
Pyrrhophyta	36399	0	18199	176112	157243	166678	12451	37354	24903	-	-	-
Euglenophyta	145595	84930	115261	257394	181434	219414	186770	298833	242802	132127	108104	120115
Others	109196	109196	109196	785730	858788	822260	821790	871595	846692	120115	72069	96093
Total	1,795,671	1,360,098	1,577,875	2,858,430	2,419,123	2,638,782	2,440,461	2,406,848	2,423,662	1,393,344	1,312,867	1,353,106

APPENDIX TABLE E-3
(continued)
PHYTOPLANKTON COMPOSITION AND DENSITY (no./liter)
STATIONS 1, 2, 4 AND 6
CLARKS HILL LAKE
30 APRIL 1981

Taxon	Station and replicate											
	1			2			4			6		
	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
CHLOROPHYTA (continued)												
Pediastrum obtusum	0	5605	2803									
Quadrigula lacustris	0	5605	2803	14014	0	7007				0	6206	3103
Scenedesmus acutiformis	16816	5605	11211							0	6206	3103
S. bijuga	11211	0	5605									
S. quadricauda	0	5605	2803				6606	6606	6606	0	6206	3103
S. serratus				4671	0	2336						
Scenedesmus spp.	5605	0	2803	9342	4671	7007	13213	19819	16516	12412	0	6206
Schoederia setigera										6206	6206	6206
Selenastrum minutum	0	11211	5605									
Sphaerocystis schroeteri	11211	44843	28027	28027	88752	58389	39638	99095	69367	80678	105501	93089
Staurastrum curvatum				4671	0	2336				6206	0	3103
Tetrastrum punctatum	5605	28027	16816									
Tetraedron minimum	0	5605	2803	4671	0	2336				6206	6206	6206
Volvox tertius				0	4671	2336						
coccoid green sp.	0	11211	5605				19819	0	9910			
CRYPTOPHYTA												
cryptophyte spp.	252242	437220	344731	140135	471786	305960	554933	759729	657331	614390	515095	564742
CYANOPHYTA												
Anacystis spp.	11211	5605	8408	C	18684	9342	6606	19819	13213	0	6206	3103
Aphanothece sp.				28027	4671	16349						
Chroococcus dispersus	50448	39238	44843	9342	23356	16349	66063	85882	75973	80678	24824	52751
Dactylococcopsis fascicularis				0	4671	2336						
D. smithii	22422	22422	22422	4671	9342	7007	26425	39638	33032	37236	62060	49648
Merismopedia tenuissina							6606	0	3303			
Oscillatoria spp.				0	5138	2569						
PYRRHOPHYTA												
Glenodinium pulvisculus							6606	0	3303			
Peridinium inconspicuum				0	9342	4671	0	13213	6604			
Peridinium sp.				4671	0	2336						
dinoflagellate spp.	0	5605	2803									
EUGLENOPHYTA												
Euglena sp.				4671	0	2336	6606	0	3303			
euglenoid sp.							13213	6606	9910			
Trachelomonas spp.				4671	0	2336						
OTHER												
phytoflagellate spp. >10μ	0	5605	2803	4671	28027	16349	46244	72670	59457	0	6206	3103
phytoflagellate spp. <10μ				9342	14014	11678	13213	13213	13213	6206	0	3103
TOTAL PHYTOPLANKTON	936,098	1,104,257	1,020,182	780,082	1,070,159	925,128	1,347,691	1,651,584	1,499,635	1,154,312	1,030,191	1,092,251

TABLE E-4

SUMMARY OF PHYTOPLANKTON DENSITY (no./liter)
CLARKS HILL LAKE
30 APRIL 1981

	Station and replicate											
	1			2			4			6		
Taxon	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Bacillariophyta	274663	224215	249440	355009	205530	280271	303891	363347	333620	124120	155149	139635
Chrysophyta	-	-	-	-	-	-	-	13213	6606	-	-	-
Chlorophyta	325112	364347	344732	214872	275598	245239	297285	264254	280767	291682	260651	276166
Cryptophyta	252242	437220	344731	140135	471786	305960	554933	759729	657331	614390	515095	564742
Cyanophyta	84081	67265	75673	42040	65862	53952	105700	145339	125521	117914	93090	105502
Pyrrhophyta	-	5605	2803	4671	9342	7007	6606	13213	9907	-	-	-
Euglenophyta	-	-	-	9342	-	4672	19819	6606	13213	-	-	-
Others	-	5605	2803	14013	42041	28027	59457	85883	72670	6206	6206	6206
Total	936,098	1,104,257	1,020,182	780,082	1,070,159	925,128	1,347,691	1,651,584	1,499,635	1,154,312	1,030,191	1,092,251

	Station and replicate											
	3			5			7			8		
Taxon	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Bacillariophyta	383166	297284	340226	784435	1221334	1002884	520251	586314	553283	347535	448434	397981
Chrysophyta	13213	-	6606	-	-	-	-	-	-	-	-	-
Chlorophyta	422804	356740	389772	397185	466691	431936	404636	404637	404640	571754	515697	543720
Cryptophyta	59457	151946	105702	317745	784433	551089	536765	966178	751471	100897	11211	56054
Cyanophyta	218009	112307	165158	188662	466688	327675	99095	175894	137496	504487	336323	420402
Pyrrhophyta	72670	26425	49548	-	-	-	-	-	-	-	-	-
Euglenophyta	6606	19819	13213	-	19959	9930	-	-	-	33633	11211	22421
Others	19819	33032	26425	39719	89366	64542	41290	24774	33032	33632	-	16816
Total	1,195,744	997,553	1,096,650	1,727,746	3,046,371	2,388,556	1,102,037	2,157,797	1,879,922	1,591,938	1,322,876	1,457,394

APPENDIX TABLE E-4
(continued)
PHYTOPLANKTON COMPOSITION AND DENSITY (no./liter)
STATIONS 3, 5, 7 AND 8
CLARKS HILL LAKE
30 APRIL 1981

Taxon	Station and replicate											
	3			5			7			8		
	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
CHLOROPHYTA (continued)												
Miractinium pusillum	0	6606	3303				0	8258	4129	0	11211	5605
Oocystis Borgei	13213	6606	9910									
O. parva	6606	6606	6606	29789	49648	39718	16516	24773	20645	11211	22422	16816
O. pusilla	46244	33032	39638	19859	9930	14894	8258	8258	8258	11211	0	5605
Pediastrum duplex				9930	0	4965						
Polyedriopsis quadrispina	6606	0	3303									
Quadrigula lacustris	0	6606	3303	9930	0	4965				0	11211	5605
Scenedesmus acutiformis	6606	0	3303									
S. bijuga										11211	11211	11211
S. quadricauda	6606	6606	6606	29789	0	14894	8258	0	4129			
Scenedesmus spp.	26425	13213	19819	29789	39718	34753				89686	0	44843
Schoederia setigera							33032	24774	28903	0	11211	5605
S. westii	6606	0	3303									
Sphaerocystis schroeteri	72670	19819	46244	129084	109225	119154	132127	140384	136256	168161	123318	145740
Tetrastrum glabrum				9930	0	4965						
Tetraedron minimum							8257	16516	12387			
T. muticum				0	9930	4965				0	11211	5605
coccoid green spp.	13213	6606	9910	29789	0	14894	8258	0	4129	33632	22422	28027
CRYPTOPHYTA												
cryptophyte spp.	59457	151946	105702	317745	784433	551089	536765	966178	751471	100897	11211	56054
CYANOPHYTA												
Anabaena macrospora v. robusta							0	18993	9497			
Anacystis spp.	19819	6606	13213	29789	89366	59577	16516	49548	33032	22422	11211	16816
Aphanothece sp.	13213	0	6606	19859	0	9930				0	11211	5605
Chroococcus dispersus	125520	72670	99095	129084	248238	188661	74321	49547	61935	280269	179372	229821
Dactylococcopsis fascicularis				0	49648	24824						
D. rhaphidioides										22422	0	11211
D. Smithii	59457	26425	42941	0	79636	39718	8258	49548	28903	67265	89686	78475
Gomphosphaeria lacustris				9930	0	4965				11211	0	5605
G. lacustris v. compacta										11211	0	5605
Merismopedia tenuissima	0	6606	3303							56054	33632	44843
Synechococcus aeruginosus										11211	0	5605
Synechocystis aquatilis										22422	11211	16816
Oscillatoria spp.							0	8258	4129			
PYRRHOPHYTA												
Peridinium inconspicuum	72670	26425	49548									
EUGLENOPHYTA												
Euglena sp.	0	19819	9910							0	11211	5605
euglenoid sp.	6606	0	3303							11211	0	5605
Trachelmonas spp.				0	19859	9930				22422	0	11211
OTHER												
phytoflagellate spp. >10μ	13213	33032	23122	29789	89366	59577	24774	0	12387	33632	0	16[illegible]
phytoflagellate spp. <10μ	6606	0	3303	9930	0	4965	16516	24774	20645			
TOTAL PHYTOPLANKTON	1,195,744	997,553	1,096,6[illegible]	1,727,746	3,048,371	2,388,05[illegible]	1,602,037	2,157,797	1,879,922	1,591,938	[illegible]	1,457,394

TABLE E-5

SUMMARY OF PHYTOPLANKTON DENSITY (no./liter)
CLARKS HILL LAKE
25 JUNE 1981

	Station and replicate											
	1			2			4			6		
Taxon	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Bacillariophyta	772953	1347148	1060051	1113054	1007050	1060055	706700	949629	828165	954046	1007050	980551
Chrysophyta	-	-	-	-	-	-	-	-	-	-	-	-
Chlorophyta	2561789	2208439	2385117	2729631	2994646	2862144	1567991	1479654	1523825	1775586	1722583	1749089
Cryptophyta	-	-	-	-	-	-	331266	375435	353351	318016	53003	185510
Cyanophyta	737620	697868	717745	812265	217311	514789	1649705	1583452	1616581	1309164	853341	1081255
Pyrrhophyta	88337	66252	77295	26501	-	13251	22084	-	11042	79504	79503	79504
Euglenophyta	22084	-	11042	26501	26501	26501	154591	66253	110422	-	26501	13251
Others	66253	-	33127	26501	-	13251	309182	198760	253971	212010	106005	159008
Total	4,249,036	4,319,707	4,284,377	4,734,453	4,245,508	4,489,991	4,741,519	4,653,183	4,697,357	4,648,326	3,847,986	4,248,168

	Station and replicate											
	3			5			7			8		
Taxon	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Bacillariophyta	1113053	1060050	1086555	1424446	795039	1109745	927544	1126304	1026927	861293	1325066	1093181
Chrysophyta	-	-	-	-	-	-	-	-	-	-	-	-
Chlorophyta	1696081	1802089	1749089	2583878	2981398	2782646	949626	1347148	1148389	3080777	2086979	2583878
Cryptophyta	53003	185509	119256	563153	927545	745349	-	-	-	563153	828166	695660
Cyanophyta	1545025	1929295	1737162	1441008	960672	1200841	958463	1146181	1052324	2557375	1619893	2088635
Pyrrhophyta	53002	-	26502	99380	66253	82817	154590	132506	143549	66253	33127	49691
Euglenophyta	265013	185509	225261	99380	198759	149070	110422	22084	66253	132506	198760	165633
Others	291515	344517	318017	165633	165633	165633	110422	88338	99380	165633	66253	115943
Total	5,016,692	5,506,969	5,261,842	6,376,878	6,095,299	6,236,101	3,211,067	3,862,561	3,536,822	7,426,990	6,158,244	6,792,621

TABLE E-6

SUMMARY OF PHYTOPLANKTON DENSITY (no./liter)
CLARKS HILL LAKE
24 AUGUST 1981

	Station and replicate											
	1			2			4			6		
Taxon	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Bacillariophyta	373237	165657	269449	332036	442302	387170	1317078	940770	1128924	367241	220345	293795
Chrysophyta	20735	-	10368	-	-	-	-	-	-	40804	138735	89770
Chlorophyta	470003	546053	508032	1128924	2106200	1617564	1693385	2320565	2006975	1028274	775286	901783
Cryptophyta	138235	110438	124337	166018	42124	104071	250872	250872	250872	16322	-	8161
Cyanophyta	65662	101847	83757	657132	1187897	922666	7526153	6742180	7134167	195046	168931	181989
Pyrrhophyta	-	6135	3068	16602	105310	60956	-	62718	31359	16322	40805	28564
Euglenophyta	27648	6135	16892	116213	63186	89700	125436	62718	94077	32644	16322	24484
Others	145147	104303	124725	99611	147434	123523	250872	125436	188154	81609	97931	89770
Total	1,240,667	1,040,568	1,140,628	2,516,836	4,094,453	3,305,650	11,163,796	10,505,259	10,834,528	1,778,262	1,458,355	1,618,316

	Station and replicate											
	3			5			7			8		
Taxon	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Bacillariophyta	564462	993035	778751	466621	752616	609620	808780	657134	732960	2046174	1511020	1778597
Chrysophyta	-	-	-	105366	30105	67736	-	-	-	-	-	-
Chlorophyta	2759590	2456453	2608026	1023556	948296	985922	4802139	4802136	4802142	3810114	2605205	3207662
Cryptophyta	-	-	-	255889	240837	248363	101098	202195	151641	493904	364729	429316
Cyanophyta	7751933	5937299	6844620	623165	367275	495222	3417099	3679952	35485209	55520889	4689372	5121130
Pyrrhophyta	62718	52265	57492	30104	45157	37631	101098	101098	101098	-	-	-
Euglenophyta	376308	365855	371082	105367	30104	67736	151646	353842	252744	635019	312625	473822
Others	188154	104530	146342	135471	225785	180628	101098	-	50549	352788	364729	358759
Total	11,703,165	9,909,437	10,806,313	2,745,539	2,640,175	2,692,858	9,482,958	9,796,357	9,639,663	12,890,888	9,847,680	11,369,286

TABLE E-7

SUMMARY OF PHYTOPLANKTON DENSITY (no./liter)
CLARKS HILL LAKE
28 OCTOBER 1981

Taxon	Station and replicate 1 A	1 B	1 $\bar{x}$	2 A	2 B	2 $\bar{x}$	4 A	4 B	4 $\bar{x}$	6 A	6 B	6 $\bar{x}$
Bacillariophyta	232891	281074	256985	706701	574193	640450	378592	441688	410143	273848	362186	318018
Chrysophyta	-	-	-	-	-	-	-	-	-	8834	17668	13251
Chlorophyta	497904	473811	485864	1280893	1347146	1314021	1346102	1703658	1524886	388687	538863	463777
Cryptophyta	152583	200767	176675	1744668	993798	1369233	1156803	1472294	1314549	61836	88338	75087
Cyanophyta	420810	551709	486262	640447	817122	728786	824486	715115	769803	400170	810058	605115
Pyrrhophyta	-	16061	8031	-	-	-	21033	-	10517	-	8834	4417
Euglenophyta	16061	48184	32123	66253	132506	99380	147230	63099	105165	8834	17668	13251
Others	24092	-	12046	88338	44169	662054	126197	63098	94648	-	26501	13251
Total	1,344,341	1,571,606	1,457,986	4,527,300	3,908,^34	4,218,124	4,000,443	4,458,952	4,229,711	1,142,209	1,870,116	1,506,167

Taxon	Station and replicate 3 A	3 B	3 $\bar{x}$	5 A	5 B	5 $\bar{x}$	7 A	7 B	7 $\bar{x}$	8 A	8 B	8 $\bar{x}$
Bacillariophyta	609951	904411	757185	1030367	806375	918375	729097	564460	646781	622059	829411	725738
Chrysophyta	-	-	-	-	-	-	-	-	-	-	23039	11520
Chlorophyta	1766755	2271543	2019157	2822310	3315097	368708	1481711	1340597	1411158	1290193	1336273	1313240
Cryptophyta	420656	715114	567885	851172	1299157	1075165	1317077	1575788	1446432	714217	783334	748776
Cyanophyta	1009573	807660	908619	2383281	2477360	2430324	423345	540943	482145	340980	541422	441203
Pyrrhophyta	-	42066	21033	89597	-	44799	70558	70558	70558	92156	23039	57599
Euglenophyt	63099	84131	73616	179195	44799	111998	164636	141116	152876	46078	115196	80638
Others	189295	105164	147230	-	-	-	-	23519	11760	23039	-	11520
Total	4,059,329	4,930,089	4,494,725	7,355,922	7,942,788	7,649,369	4,186,424	4,256,981	4,221,710	3,128,722	3,651,714	3,390,234

TABLE E-8

STATISTICAL COMPARISON OF PHYTOPLANKTON DENSITY
CLARKS HILL LAKE
FEBRUARY - OCTOBER 1981

ANALYSIS OF VARIANCE: STATIONS X MONTHS

Source	DF	Sum of squares	Mean square	
Model	39	43.93431920	1.12652101	
Error	40	1.02257989	0.02556450	
Corrected total	79	44.95689909		
Source	DF	Type I SS	F value	PR > F
Month	4	23.09087170	225.81	0.0001
Station	7	9.46967879	52.92	0.0001
Month x station	28	11.37376871	15.89	0.0001

DUNCAN'S MULTIPLE RANGE TEST: STATIONS[a]

Grouping	Mean	N	Station
A	15.145899	10	5
A	15.109583	10	7
A	15.060090	10	8
A	15.059610	10	4
A	15.029287	10	3
B	14.703260	10	2
C	14.286652	10	1
C	14.271053	10	6

DUNCAN'S MULTIPLE RANGE TEST: MONTHS[a]

Grouping	Mean	N	Month
A	15.391036	16	June
A	15.341447	16	August
B	15.042804	16	October
C	14.284546	16	February
D	14.106063	16	April

[a]Means with the same letter are not significantly different.
Alpha level=0.05; DF=40; MS=0.0255645

TABLE E-9

AVERAGE CHLOROPHYLL-a (mg/m^3)
CLARKS HILL LAKE
FEBRUARY-OCTOBER 1981

	Month					
Station	February	April	June	August	October	Average
1	3.31	1.99	2.38	1.38	3.42	2.49
2	2.98	4.55	4.92	5.62	9.11	5.43
3	2.83	4.39	3.35	5.20	6.14	4.38
4	1.27	6.52	3.38	5.65	7.81	4.92
5	10.02	7.54	5.93	3.44	8.99	7.18
6	2.34	3.09	3.28	2.72	4.27	3.14
7	8.45	5.04	6.49	8.26	10.75	7.79
8	1.92	4.69	5.94	12.69	6.02	6.25
Average	4.14	4.72	4.45	5.62	7.06	

TABLE E-10

STATISTICAL COMPARISON OF CORRECTED CHLOROPHYLL-a
CLARKS HILL LAKE
FEBRUARY - OCTOBER 1981

ANALYSIS OF VARIANCE: STATIONS X MONTHS

Source	DF	Sum of squares	Mean square
Model	39	15.19347032	0.38957616
Error	39	0.29584534	0.00758578
Corrected total	78	15.48931566	

Source	DF	Type I SS	F value	PR > F
Station	7	6.66558936	125.53	0.0001
Month	4	2.58456043	85.18	0.0001
Station x month	28	5.94332053	27.98	0.0001

DUNCAN'S MULTIPLE RANGE TEST: STATIONS[a]

Grouping	Mean	N	Station
A	2.146326	10	7
B	2.051242	10	5
C	1.853620	9	8
C	1.815088	10	2
D	1.675049	10	4
D	1.654242	10	3
E	1.406003	10	6
F	1.224634	10	1

DUNCAN'S MULTIPLE RANGE TEST: MONTHS[a]

Grouping	Mean	N	Month
A	2.036769	16	October
B	1.764162	16	August
C	1.699539	16	April
C	1.640927	15	June
D	1.486686	16	February

[a]Means with the same letter are not significantly different.
Alpha level=0.05; DF=39; MS=0.0075858

TABLE E-11

STATISTICAL COMPARISON OF PHAEOPIGMENTS
CLARKS HILL LAKE
FEBRUARY - OCTOBER 1981

ANALYSIS OF VARIANCE: STATIONS X MONTHS

Source	DF	Sum of squares	Mean square
Model	39	17.40990940	0.44640793
Error	39	2.07985615	0.05332964
Corrected total	78	19.48976555	

Source	DF	Type I SS	F value	PR > F
Station	7	2.05061734	5.49	0.0002
Month	4	11.62076138	54.48	0.0001
Station x month	28	3.73853068	2.50	0.0041

DUNCAN'S MULTIPLE RANGE TEST: STATIONS[a]

Grouping	Mean	N	Station
A	0.905726	10	3
A	0.841231	9	8
A	0.810967	10	4
A	0.776879	10	5
B	0.562368	10	1
B	0.561004	10	2
B	0.559311	10	6
B	0.431769	10	7

DUNCAN'S MULTIPLE RANGE TEST: MONTHS[a]

Grouping	Mean	N	Month
A	1.164497	16	February
B	0.840830	15	June
B	0.717540	16	October
B	0.682893	16	August
C	0.000000	16	April

[a]Means with the same letter are not significantly different.
Alpha level=0.05; DF=39; MS=0.0533296

F. ZOOPLANKTON

INTRODUCTION

Zooplankters are aquatic invertebrates that have limited mobility or passively drift with water currents. Generally, zooplankton are representative of the second trophic level in aquatic food chains. They are the major consumers of primary producers such as phytoplankton and, in turn, provide an important food source for larger macroinvertebrates and fishes.

Zooplankters are sensitive to changes within their ecosystem. Zooplankton community composition and density reflect the influences of temperature, pH, water movement, food availability, pollutants and various other physicochemical parameters. Zooplankton populations of a lake environment such as that at Clarks Hill are likely to vary considerably in both space and time.

This section examines zooplankton community composition and density at eight stations in Clarks Hill Lake during 1981. The objectives of this investigation were to establish baseline data for future comparisons and to characterize the existing zooplankton community in reference to the lake's trophic status.

MATERIALS AND METHODS

Zooplankton collections were made during February, April, June, August and October 1981 at Clarks Hill Stations 1 through 8 (Figure A-1). Collections were made with paired bongo nets of 80μ-mesh with 20.0-cm mouth diameter and 2-m length. Double oblique tows were made at each station by towing the nets at a constant speed from the surface to the bottom and then back to the surface. Tow duration averaged 5 minutes with approximately 6000 liters of water filtered through each net. The volume of flow through the bongo nets was measured with General Oceanics Model 2030 flowmeters attached in the mouth of each net housing. Zooplankton samples were preserved immediately after collection in a 5-percent formalin solution buffered with sodium borate to pH 7-8.

In the laboratory, samples were allowed to settle for a minimum of 48 hours and then were concentrated to a workable volume for analysis. The final concentrate volume of the sample was determined by the amount of detritus and the density of zooplankters in the sample.

Zooplankton identifications and counts were made by placing a well-mixed aliquot of concentrate into a 1-ml Sedgwick-Rafter counting chamber. The contents of the entire chamber were enumerated at 100X magnification. When densities allowed, a minimum of 100 organisms were examined from each of two identically prepared chambers per replicate. Zooplankters were identified to the lowest practicable taxon.

The number of zooplankters per liter (N) was calculated by:

$$N = \frac{\frac{V_c}{V_e} C}{V_f}$$

where: V_c = Volume of sample concentrate, in milliliters;

V_e = Volume of concentrate examined, in milliliters;

C = Number of zooplankters counted; and

V_f = Volume of water filtered, in liters.

Whole zooplankton samples were retained as vouchers.

For statistical analysis, zooplankton data were transformed to $\log_e$(number per liter + 1) to reduce the effect of nonuniform variation and skewness in these data. Both geometric and arithmetic means were calculated. The Statistical Analysis System (SAS; Barr et al., 1976) was used in all statistical analyses. The General Linear Models (GLM) Procedure, which provides the regression approach to analysis of variance, was used to examine interstation and seasonal variation in zooplankton density at the 0.05 level of significance. Duncan's multiple range tests were used to determine which means were significantly different.

RESULTS AND DISCUSSION

Community Composition

The zooplankton species collected at Clarks Hill Lake were typical of other freshwater communities (Hutchinson, 1967; Hynes, 1970). Rotifers and crustaceans predominated the zooplankton community throughout the year (Appendix Tables F-1 through F-10).

Overall, rotifers were the most abundant organisms in terms of density and number of taxa observed. Annually, rotifers averaged 61 percent of the total zooplankton density (ranging from 16 percent in February to 86 percent in October) and were represented by 31 taxa (Tables F-1 through F-6). Keratella cochlearis and Polyarthra vulgaris were predominant rotifers and were consistently observed at all lake and riverine stations. These two species were predominant taxon observed from Lake Sidney Lanier during a similar water quality management study (ESE, 1981). These perennial zooplankton species are eurytrophic and have a cosmopolitan distribution (Ruttner-Kolisko, 1974). Other frequently observed genera included species of Asplanchna, Hexarthra, Kellicottia, Ploesoma, Synchaeta and Trichocerca.

Rotifers are an important constituent of the zooplankton community in Clarks Hill Lake. They feed on algae and bacteria and provide an important food source for crustaceans and larger macroinvertebrates. The species composition of rotifer populations did not vary significantly among stations but did demonstrate wide seasonal variation. For example, the aestival species Ploesoma triacanthum and Hexarthra mira were not observed until June, when ambient water temperatures exceeded 25°C.

Rotifers are opportunistic organisms which have short generation and maturation rates that allow them to quickly take advantage of favorable environmental conditions. Shifts in population composition and abundance occur rapidly and are related to changes in temperature, food availability and other physicochemical parameters (Williams, 1966). Peak abundance of rotifers occurred in October when phytoplankton standing crop was high and ambient water temperatures were favorable for reproduction (16° to 20°C).

Copepods were the second most abundant group, averaging over 30 percent of the total zooplankton. Copepod nauplii and cyclopoid copepodids dominated the zooplankton in February and April and were recorded at all stations in subsequent sampling periods. Seven species of adult copepods were observed: the calanoids Diaptomus mississippiensis and D. pallidus, and the cyclopoids Tropocyclops prasinus prasinus, Cyclops bicuspidatus thomasi, C. vernalis, Mesocyclops edax and Eucyclops agilis. Tropocyclops prasinus prasinus was the only copepod species observed throughout the study period. The other copepod taxa were recorded less frequently and in low densities. The copepod species observed at Clarks Hill are common planktonic and littoral inhabitants of rivers and lakes. Species composition was similar to those reported from other regional investigations of similar habitat type (Duke Power Company, 1978; U.S. Army Corps of Engineers, 1978, 1981).

The cladoceran community at Clarks Hill Lake was composed of 19 species, of which Bosmina longirostris was the predominant taxa. Other frequently observed species included Diaphanosoma leuchtenbergianum and Holopedium amazonicum. Annually, cladocerans accounted for less than 10 percent of the total zooplankton community. Monthly averages ranged from approximately 2 percent in October to almost 26 percent in February. Considerable temporal and spatial variation in cladoceran density and composition was observed. Limnetic as well as pelagic cladoceran species were identified at both lake and riverine stations. No consistent trend of cladoceran distribution or frequency of occurrence was observed among stations.

Density Trends

Zooplankton densities demonstrated significant seasonal variation (Table F-7). Generally, Density trends showed a biomodal pattern of peak occurrence, with population increases in April and October (Figure F-1). The observed peak zooplankton density (310.83 zooplankters per liter) occurred at Station 3 in October, and the lowest recorded zooplankton density for any station was 5.67 individuals per liter at Station 8 in February. Temporal changes in zooplankton density and composition result, in part, from biotic and abiotic interactions within the environment. Most zooplankton species exist under a wide range of environmental conditions where growth and reproduction become optimal. Because the zooplankton community at Clarks Hill Lake is represented by a diverse group of organisms, each with specific requirements, variations in density and composition of the community are likely to occur in both space and time. Zooplankters respond to changes in physicochemical parameters through a succession of species that are most tolerant of existing conditions. Seasonal zooplankton variation between and among groups are normal occurrences.

Interstation comparison of variation in zooplankton densities showed significant differences among stations (Tables F-7 and F-8). However, significant interaction, as indicated by analysis of variance, demonstrated that density variation among stations was not consistent between sampling periods. Localized habitat differences among stations were probably responsible for the observed variations in zooplankton densities. The results of statistical evaluation of zooplankton densities showed a clear trend of higher productivity at those stations located in tributaries or rivers entering Clarks Hill Lake (Tables F-2 through F-6). Stations 5 and 7, located in the Georgia Little River and South Carolina Little River, respectively, are examples. Increased productivity in these areas most likely results from high food availability and nutrient concentrations, such as phosphorus (Section B). Rivers are usually the major source of nutrient loading to lakes or reservoirs because of discharges of municipal and industrial pollutants and hydrodynamic interactions between river and lake water masses (Gannon and Stemberger, 1978). Phytoplankton standing crop at Clarks Hill Lake was highest at the riverine stations (Section E). Total zooplankton density and chlorophyll-a levels were significantly correlated with each other (r = 0.643; critical r value at P = 0.05, 38 df, = 0.304).

Although zooplankton densities were generally higher at stations in riverine environments, no trend of reduced species diversity was observed between riverine and lake stations. The major waterways entering Clarks Hill Lake provide an important source of zooplankton recruitment to the lake.

Because Clarks Hill Lake is an impoundment, its water quality and its productivity reflects the various streams and rivers entering it. Clarks Hill Lake was ranked sixth in overall trophic quality of 14 Georgia lakes and reservoirs sampled in 1973 (EPA, 1976). That survey indicated that Clarks Hill Lake was meso-eutrophic. However, the trophic classification of major waterways entering the lake (Savannah, Broad, South Carolina and Georgia Little Rivers) were eutrophic. Evidence of nutrient loading at stations located in the Georgia and South Carolina Little River was observed during the 1981 Water Quality study (Section B). High zooplankton densities observed at these stations are most likely in response to high food availabilty as a result of increased nutrient levels.

SUMMARY

Eight stations located in Clarks Hill Lake were sampled for zooplankton density and composition during February, April, June, August and October 1981.

The zooplankton community observed at Clarks Hill Lake was similar in composition and abundance to other freshwater zooplankton communities. Rotifers were the most abundant organisms in terms of density and number of taxa observed, followed by copepods and cladocerans. Seasonally, zooplankton densities were lowest in June and highest in October. Generally, interstation comparison of zooplankton abundance indicated significantly higher densities at stations located in rivers and tributary waters entering Clarks Hill Lake. Zooplankton species composition demonstrated significant seasonal and spatial differences. These differences were attributed to habitat variation and natural succession of species through time.

The major waterways entering Clarks Hill Lake most likely provide the initial source of zooplankton production to the lake. This is concluded by the lack of significant variation in species composition between riverine and lake stations and the observation of higher zooplankton productivity in source water areas.

LITERATURE CITED

Barr, A.J., J.H. Goodnight, J.P. Sall, and J.T. Helwig. 1976. A user's guide to SAS 76. SAS Institute, Inc., Raleigh, N.C. 329 pp.

Duke Power Company. 1978. Baseline environmental summary report on the Broad River in the vicinity of Cherokee Nuclear Station. Edited by L.L. Olmsted and A.S. Leiper. 195 pp.

EPA (U.S. Environmental Protection Agency). 1976. National Eutrophication Survey. Report on Clark's Hill Reservoir. EPA Region IV. Working Paper No. 287.

ESE (Environmental Science and Engineering). 1981. Water quality management studies. Lake Sidney Lanier, Georgia. Mobile District, USCOE.

Gannon, J.E., and R.S. Stemberger. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Trans. Amer. Micros. Soc. 97(1):16-35.

Hutchinson, G.E. 1967. A treatise on limnology. Volume II. Introduction to lake biology and limnoplankton. John Wiley and Sons, New York. 1115 pp.

Hynes, H.B.N. 1970. The ecology of running waters. University of Toronto Press, Toronto, Canada. 555 pp.

Ruttner-Kolisko, A. 1974. Plankton rotifers, biology and taxonomy. Die Bennengewasser Vol. XXVI supplement. 146 pp.

U.S. Army Corps of Engineers. 1978. Water quality management studies. Technical report ACF 80-1. Lake Seminole, April-November 1978. Mobile District, USACOE.

Williams, L.G. 1966. Dominant planktonic rotifers of major waterways of the United States. Limnology Oceanography 11:83-91.

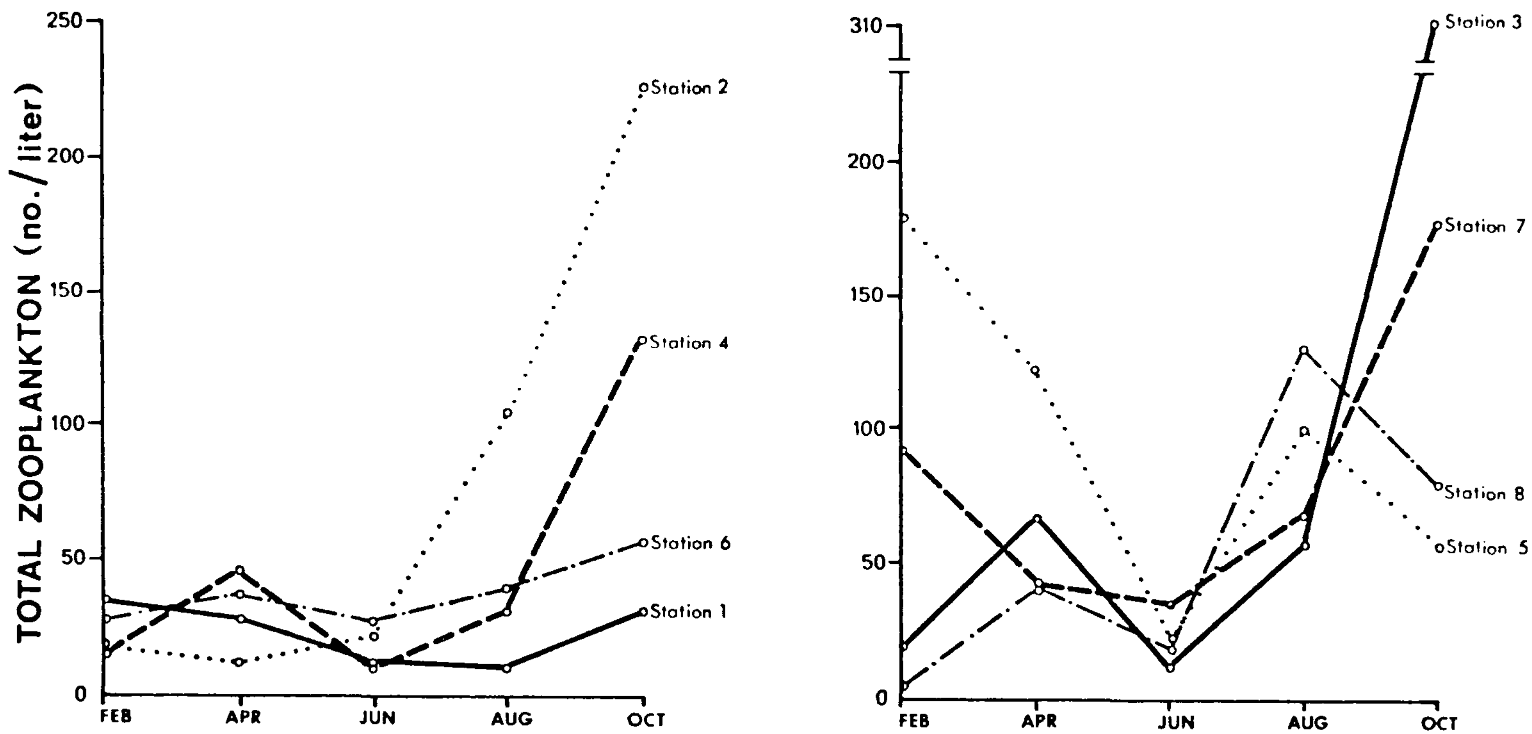


Figure F-1. Total zooplankton densities at Stations 1 through 8, Clarks Hill Lake, 1981.

TABLE F-1

COMPOSITE LIST OF ZOOPLANKTON SPECIES
CLARKS HILL LAKE
1981

PROTOZOA
- *Difflugia* sp.
- *Vorticella* sp.

ROTIFERA
- *Asplanchna* sp.
- *A. priodonta*
- *Brachionus angularis*
- *B. calyciflorus*
- *B. havanaensis*
- *B. patulus*
- *B. urceolaris*
- *Collotheca* sp.
- *Conochiloides* sp.
- *Conochilus unicornis*
- *Epiphanes* sp.
- *Euchlanis* sp.
- *Filina longiseta*
- *Gastropus stylifera*
- *Hexarthra* sp.
- *H. mira*
- *Kellicottia bostoniensis*
- *Keratella cochlearis*
- *K. valga*
- *Lecane lunaris*
- *Monostyla lunaris*
- *Noltholca labis*
- *Platyas quadricornis*
- *Ploesoma triacanthum*
- *Polyartha vulgaris*
- *Synchaeta* sp.
- *Trichocerca* sp.
- *T. capucina*
- *T. cyclindrica*
- *Trichotria* sp.
- *T. tetractis*

CLADOCERA
- *Alona costata*
- *Alonella* sp.
- *Bosmina longirostris*
- *Bosminopsis detersi*
- *Ceriodaphnia lacustris*
- *C. quadrangula*
- *Chydorus sphaericus*
- *Daphnia* sp.
- *D. ambigua*
- *D. galeata mendotae*
- *D. laevis*
- *D. parvula*
- *D. rosea*
- *Diaphanosoma leuchtenbergianum*
- *Holopedium amizonicum*
- *Ilyocryptus spinifer*
- *Leptodora kindtii*
- *Leydigia quadrangularis*
- *Pleuroxis hamulatus*

COPEPODA
- Calanoida
  - *Diaptomus mississippiensis*
  - *D. pallidus*
- Cyclopoida
  - *Cyclops bicuspidatus thomasi*
  - *C. vernalis*
  - *Eucyclops agilis*
  - *Mesocyclops edax*
  - *Tropocyclops prasinus*

OTHERS
- *Chaoborus punctipennis*
- Ostracoda
- Nematoda

TABLE F-2

BROAD GROUP ZOOPLANKTON PERCENTAGE COMPOSITION
STATIONS 1 THROUGH 8
CLARKS HILL LAKE
24 FEBRUARY 1981

	Station							
	1		2		4		6	
roup	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
rotozoa	-	-	-	-	0.05	0.32	-	-
otifera	3.42	10.09	1.18	6.70	1.58	9.96	4.88	18.28
ladocera	3.86	11.38	3.82	21.70	1.76	11.09	6.04	22.62
opepoda	26.63	78.53	12.60	71.59	12.53	78.95	15.78	59.10
thers	-	-	-	-	-	-	-	-
'otal	33.91	100.00	17.60	100.00	15.87	100.00	26.70	100.00

	Station							
	3		5		7		8	
iroup	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
'rotozoa	0.14	0.73	0.82	0.45	-	-	-	-
:otifera	5.22	27.23	39.79	21.93	2.91	3.13	2.84	50.09
.ladocera	5.73	29.89	64.81	35.72	15.69	16.87	0.94	16.58
:opepoda	8.08	42.15	76.00	41.89	74.41	80.00	1.89	33.33
)thers	-	-	-	-	-	-	-	-
'otal	19.17	100.00	181.42	100.00	93.01	100.00	5.67	100.00

:HVI
'ABLEF-2

TABLE F-3

BROAD GROUP ZOOPLANKTON PERCENTAGE COMPOSITION
STATIONS 1 THROUGH 8
CLARKS HILL LAKE
30 APRIL 1981

	Station							
	1		2		4		6	
Group	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
Protozoa	-	-	-	-	-	-	-	-
Rotifera	1.06	3.82	1.64	12.18	18.08	39.24	13.47	36.71
Cladocera	10.22	36.87	1.64	12.18	3.20	6.95	2.71	7.39
Copepoda	16.44	59.31	10.16	75.48	24.79	53.81	20.51	55.90
Others	-	-	0.02	0.15	-	-	-	-
Total	27.72	100.00	13.46	100.00	46.07	100.00	36.69	100.00

	Station							
	3		5		7		8	
Group	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
Protozoa	-	-	-	-	-	-	-	-
Rotifera	43.52	65.19	81.19	66.63	8.67	19.89	33.15	77.80
Cladocera	3.38	5.06	5.19	4.26	5.51	12.64	1.04	2.44
Copepoda	19.47	29.16	34.93	28.67	29.08	66.73	8.38	19.67
Others	0.39	0.58	0.54	0.44	0.29	0.67	0.04	0.09
Total	66.76	100.00	121.85	100.00	43.58	100.00	42.61	100.00

TABLE F-4

BROAD GROUP ZOOPLANKTON PERCENTAGE COMPOSITION
STATIONS 1 THROUGH 8
CLARKS HILL LAKE
26 JUNE 1981

	Station							
	1		2		4		6	
Group	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
Protozoa	-	-	-	-	-	-	-	-
Rotifera	0.65	4.56	3.35	15.71	2.82	28.34	3.08	11.54
Cladocera	2.79	19.58	6.53	30.63	0.63	6.33	0.85	3.18
Copepoda	10.81	75.86	11.44	53.66	6.50	65.33	22.76	85.28
Others	-	-	-	-	-	-	-	-
Total	14.25	100.00	21.32	100.00	9.95	100.00	26.69	100.00

	Station							
	3		5		7		8	
Group	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
Protozoa	-	-	-	-	-	-	-	-
Rotifera	3.04	26.09	9.89	47.01	22.27	63.68	11.29	53.92
Cladocera	0.62	5.32	1.25	5.94	0.63	1.80	0.69	3.30
Copepoda	7.96	68.33	9.90	47.05	11.98	34.26	8.96	42.79
Others	0.03	0.26	-	-	0.09	0.26	-	-
Total	11.65	100.00	21.04	100.00	34.97	100.00	20.94	100.00

CHVI
TABLEF-4

TABLE F-5

BROAD GROUP ZOOPLANKTON PERCENTAGE COMPOSITION
STATIONS 1 THROUGH 8
CLARKS HILL LAKE
24 AUGUST 1981

	Station							
	1		2		4		6	
Group	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
Protozoa	-	-	-	-	-	-	-	-
Rotifera	2.22	22.18	59.40	56.45	6.69	21.00	18.77	46.70
Cladocera	1.83	18.28	19.65	18.68	2.64	8.29	7.80	19.41
Copepoda	5.96	59.54	26.17	24.87	22.52	70.71	13.62	33.89
Others	-	-	-	-	-	-	-	-
Total	10.01	100.00	105.22	100.00	31.85	100.00	40.19	100.00

	Station							
	3		5		7		8	
Group	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
Protozoa	-	-	-	-	-	-	-	-
Rotifera	27.66	46.84	63.44	62.50	51.50	75.68	88.29	67.15
Cladocera	4.58	7.76	3.90	3.84	7.86	11.55	5.30	4.03
Copepoda	26.81	45.40	34.16	33.66	8.69	12.77	37.89	28.82
Others	-	-	-	-	-	-	-	-
Total	59.05	100.00	101.50	100.00	68.05	100.00	131.48	100.00

CHI
TABLEF-5

TABLE F-6

BROAD GROUP ZOOPLANKTON PERCENTAGE COMPOSITION
STATIONS 1 THROUGH 8
CLARKS HILL LAKE
24 OCTOBER 1981

	Station							
	1		2		4		6	
oup	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
otozoa	-	-	-	-	-	-	-	-
tifera	24.62	78.28	204.67	90.14	118.83	89.07	38.40	68.16
adocera	0.94	2.99	4.85	2.14	0.37	0.28	9.30	16.51
pepoda	5.89	18.73	17.55	7.73	14.21	10.65	8.64	15.34
hers	-	-	-	-	-	-	-	-
tal	31.45	100.00	227.07	100.00	133.41	100.00	56.34	100.00

	Station							
	3		5		7		8	
oup	Density	Percentage	Density	Percentage	Density	Percentage	Density	Percentage
otozoa	-	-	-	-	-	-	-	-
tifera	267.09	85.93	52.41	91.12	152.74	85.74	71.52	88.62
adocera	2.90	0.93	0.61	1.06	4.28	2.40	1.73	2.14
pepoda	40.84	13.14	4.50	7.82	21.13	11.86	7.45	9.23
hers	-	-	-	-	-	-	-	-
tal	310.83	100.00	57.52	100.00	178.15	100.00	80.70	100.00

II
BLEF-6

TABLE F-7

STATISTICAL COMPARISON OF ZOOPLANKTON DENSITY
2-WAY ANALYSIS OF VARIANCE
STATIONS 1 THROUGH 8
CLARKS HILL LAKE
1981

ANALYSIS OF VARIANCE

Source	DF	Sum of squares	Mean square	
Model	39	71.18257801	1.82519431	
Error	40	2.55703191	0.06392580	
Corrected total	79	73.73960992		
Source	DF	Type I SS	F value	PR>F
Station	7	12.95153552	28.94	0.0001
Month	4	27.59064590	107.90	0.0001
Station x month	28	30.64039659	17.12	0.0001

DUNCANS'S MULTIPLE RANGE TEST: STATIONS[a]

Alpha level=0.05 DF=40 MS=0.0679593

GROUPING		MEAN	N	STATION
	A	4.334598	10	5
	A	4.249868	10	7
	B	3.871672	10	3
C	B	3.708236	10	2
C	D	3.552685	10	8
C	D	3.533217	10	6
	D	3.414427	10	4
	E	3.043540	10	1

DUNCAN'S MULTIPLE RANGE TEST: MONTHS[a]

Alpha level=0.05 DF=40 MS=0.0679593

GROUPING	MEAN	N	MONTH
A	4.637736	16	October
B	3.964790	16	August
C	3.721070	16	April
D	3.353672	16	February
E	2.890383	16	June

[a]Means with the same letter are not significantly different.

CHI
TABLEF-7

TABLE F-8

STATISTICAL COMPARISON OF ZOOPLANKTON DENSITY
1-WAY ANALYSIS OF VARIANCE
STATIONS 1 THROUGH 8
CLARKS HILL LAKE
1981

ANALYSIS OF VARIANCE

Source	DF	Sum of squares		Mean square
Model	7	12.95153552		1.85021936
Error	72	60.78807440		0.84427881
Corrected total	79	73.73960992		
Source	DF	Type I SS	F value	PR>F
Station	7	12.19153552	2.19	0.0446

DUNCANS'S MULTIPLE RANGE TEST: STATIONS[a]

Alpha level=0.05 DF=72 MS=0.830816

GROUPING		MEAN	N	STATION
	A	4.334598	10	5
	A	4.249868	10	7
B	A	3.871672	10	3
B	A	3.708236	10	2
B	A	3.552685	10	4
B	A	3.533217	10	6
B	A	3.414427	10	8
B		3.043540	10	1

[a]Means with the same letter are not significantly different.

CHI
TABLEF-8

G. PERIPHYTON

INTRODUCTION

The purpose of periphyton sampling at the Clarks Hill Lake was to acquire baseline data for future data comparisons of periphyton composition, density and species diversity. The study was designed to provide evidence of potential environmental problems and to allow a tentative evaluation of the trophic condition of the habitat.

The term periphyton is used to describe all those aquatic organisms that attach to, but do not penetrate, submerged substrates (APHA, 1976). Plants and certain parasitic organisms that have roots or otherwise penetrate the substrate are not included. Examples of periphyton organisms include bacteria, yeasts, molds, algae, protozoa and larger colonial forms such as bryozoa. Periphyton also includes free-living organisms (i.e., rotifers, worms, larvae), which may inhabit the mat of attached forms. Because of the wide variety of plants and animals included in the periphyton community and a similarly varied range of specialized adaptations, virtually all submerged substrates (living and nonliving may be colonized.

Algae are frequently a dominant component of the periphyton community. These primary producers convert dissolved inorganic nutrients into organic matter through photosynthesis. In shallow waters, periphytic algae are thought to play a predominant role in primary production (EPA, 1973). The shallow margins of Clarks Hill Lake and its tributaries provide conditions that should support this role.

The periphyton community is widely accepted as a valuable indicator of water quality. Periphyton organisms have comparatively brief life cycles and competition for available substrate space is intense. Therefore, natural or man-induced change in habitat parameters may result in rapid qualitative and quantitative alterations in the periphyton community.

MATERIALS AND METHODS

The schedule of periphyton sample collections at Stations 1, 3, 5, 7, 9 and 11 is contained in Table A-3. Figure A-1 shows station locations and Table A-2 provides station descriptions. Collections were made with diatometers containing standard (2.5 x 7.6-cm) microscope slides. The diatometers were strapped to concrete blocks using non-metallic materials and carefully lowered to the lake bottom in approximately 1 meter of water (littoral zone). Three replicate samples (from separate diatometers) were routinely collected for species identification and counts following 4-week exposure intervals. Replicates were preserved separately in the field by immersing diatometer slides in 5-percent buffered formalin solution.

In the laboratory, all diatometer slides were scraped on both sides and detached organisms were washed back into the collection bottles. Samples were concentrated, by siphoning, to a measured concentrate volume after at least 24 hours of settling. In the event of heavy clumping, sample concentrates were homogenized in a blender and resettled.

The inverted microscope technique (Utermohl, 1958) was used for species identifications and counts. All samples were retained as references following analysis. Taxonomic references used in species identification included: Van Heurck (1896), Walton (1915), Hustedt (1930), Skuja (1948), Smith (1950), Edmondson (1959), Prescott (1962), Patrick and Reimer (1966, 1975), Weber (1966), Bick (1972), Sreenivasa and Duthie (1973), and Prescott et al. (1975).

All algal species, except certain greens and blue-greens, were counted as individual cells. Filamentous green and blue-green species were counted in 100µ unit lengths. Colonial forms exclusive of diatoms were counted as *naturally occurring colonies.* Density per square centimeter was calculated as N by:

$$N = \frac{\frac{V_s}{V_c} C}{A}$$

where:

V_s = Volume of sample concentrate, in milliliters;

V_c = Examined volume of sample concentrate, in milliliters;

C = Number of cells or units counted;

A = Area of substrate sampled, in square centimeters.

For statistical analysis, periphyton density data was transformed to $\log_e$ to reduce the effect of nonhomogeneous variation and skewness. The General Linear Models (GLM) Procedure (SAS; Barr et al. 1976), which provides the regression approach to analysis of variance, was used to examine interstation variation in periphyton data. Significance was tested at the 95-percent confidence interval.

RESULTS AND DISCUSSION

The periphyton consisted predominantly of diatoms (85 species), green algae (50 species), and blue-green algae (16 species). Other divisions/phyla were each represented by six or fewer species (Table G-1). The periphyton algae in Clarks Hill Lake was similar to floras reported in other regional studies in the southeast (USACOE, 1978; Duke Power, 1978).

The relative abundance of all periphyton divisions varied between seasons and between stations. Diatoms (Bacillariophyta) were consistently dominant, representing more than 50 percent of the total cell count, in all samples (Tables G-2 through G-4; Figure G-1). In March, diatom dominance was greatest at Station 11 where the diatom *Achnanthes microcephala* accounted for 47 percent of the total periphyton. In contrast, the relative abundance of certain non-diatom groups at Stations 3, 5 and 7 was greater in March than in any other month. The euglenophyte *Trachelomonas* sp., the protozoan *Diplosigopsis siderothece*, and small phytoflagellates occurred as major taxa (5 percent or more of the total periphyton) in March only.

In July, major periphyton taxa were confined to diatoms, green algae and blue-green algae. Composition was generally similar among stations except for the almost exclusive presence of diatoms at Station 5, where the diatom *Achnanthes minutissima* accounted for 76 percent of the total periphyton. At all stations, the densities of green algae and blue-green algae were higher during July than in March. This probably was promoted by the seasonal increase in water temperature and light intensity. Unidentified coccoid spp. comprised the major green algae taxa and predominant blue-green species included *Chroococcus dispersus* and *Oscillatoria* spp.

Diatom dominance was greatest in the October samples, with predominant species including *Achnanthes microcephala*, *Gomphonema gracile*, *G. parvulum* and *Synedra rumpens*. Generally, the environmental requirements of these and most of the other major diatom species at Clarks Hill Lake (Table G-5) reflect conditions that are typical of many lakes and reservoirs. Most of these species prefer circumneutral to alkaline pH, and are tolerant of varying current conditions (Lowe, 1974). The distribution of diatom species growing among stations did not reflect consistent, long-term variation in growing conditions over the three sampling periods.

Total periphyton densities varied extensively among stations and among sampling dates (Figure G-2). Densities (numbers/cm^2) ranged from 1.9×10^3 to 843×10^3 individuals per cm^2. Minimum densities occurred in March at all stations, except Station 11 where minimum density occurred in October. Density maxima occurred at Stations 1, 3 and 11 in

July and at Stations 5, 7 and 9 in October. As a result of inconsistent variation in density among stations over the monitoring period, overall interstation differences in mean periphyton densities were not statistically significant (Table G-6).

The inconsistent seasonal variation among locations within the lake and below the dam suggested that localized effects such as shoreline turbidity, nutrient concentrations and current velocity were more important than seasonal influences in determining periphyton growth. Stations 5, 7, 9 and 11 were subject to currents, whereas Stations 1 and 3 were relatively uninfluenced. Over the three collection periods, consecutive decreases in periphyton densities at Station 11 corresponded to consecutive reductions in discharge volume at Clarks Hill Lake (Table A-1) and to consecutive increases in turbidity below the dam (Appendix Tables B-46 through 51). Low dissolved oxygen levels below Clarks Hill Dam during summer, when the lake was stratified (Figure B-10), had little or no effect on the periphyton community. Periphyton density at Station 11 showed no direct relationship with dissolved oxygen levels. Maximum density was observed during the period of lower dissolved oxygen levels (July) while minimum densities were observed when dissolved oxygen levels were higher (October). Current velocity and turbidity were likely the most important factors controlling periphyton density below Clarks Hill Dam.

The occurrence of comparatively high densities in the lake at Stations 5, 7 and 9 were also related to changes in current velocities and turbidity levels of the Savannah River, South Carolina Little River and Georgia Little River. Gentler current flow may stimulate periphyton growth by supplying dissolved nutrients and CO_2, and by removing wastes (Whitfield and Schumacher, 1961, 1964; McIntyre, 1966), while strong currents such as those encountered below Clarks Hill Dam may reduce periphyton abundance through scouring (Starrett and Patrick, 1952). Variations in periphyton density among Stations 5, 7 and 9 were closely associated with changes in turbidity values (Appendix Tables B-46 through 51). Elevated periphyton densities frequently corresponded to lower turbidity values, and diminshed growth corresponded to increased turbidity. These results indicated that turbidity, by restricting light penetration to submerged substrates, was a major factor influencing periphyton growth in the lake. The potential influence of light on periphyton growth has been documented under experimental conditions (Phinney and McIntyre, 1965).

Station 9 on the the Savannah River was compared to Stations 5 and 7 on the Georgia and South Carolina Little Rivers because of potential effects related to construction of the Richard B. Russell Dam approximately 5 kilometers upstream from Station 9. Average periphyton density at Station 9 was slightly higher than at Stations 5 and 7, although this difference was not statistically significant. Seasonal changes in were similar among these stations and overall physicochemical parameters were generally similar at comparable depths. Effects from construction of the Richard B. Russell Dam were not apparent at Station 9.

Periphyton species diversity was examined lakewide on the basis of species numbers, the Shannon-Weaver diversity index, and species equitability (Table G-7). There was extensive variability in diversity between stations and no trends were apparent with the exception that all diversity parameters were lowest at Station 5 during two of the three collection periods.

In undisturbed habitats, periphyton communities typically include a few species in high densities and many species with low densities. Various forms of pollution affect cell reproduction eliminating many of the less abundant species and allowing a very limited number of pollution-tolerant species to become excessively dominant (Patrick, 1970). Extreme dominance (76 percent of the total periphyton) by the diatom *Achnanthes minutissima*, and reduction of all diversity parameters at Station 5, may reflect environmental stress caused by phosphate loading in the Georgia Little River. Average total phosphate was much higher at Station 5 than at any other station and total phosphate concentration in the Georgia Little River has increased over 500 percent since 1973 (Table B-4). Over the three sampling periods, however, periphyton community structure was generally diverse throughout the lake, did not exhibit excessive dominance of eutrophic indicator species such as *Melosira varians* and *M. granulata* and, therefore, did not reflect lakewide pollution effects.

SUMMARY

Periphyton composition in Clarks Hill Lake was typical of communities reported in other southeastern impoundments. Diatoms were the dominant taxa and the relative abundance of all major groups, including green algae and blue-green algae, varied seasonally. Distribution of individual species among stations did not show consistently different littoral habitat conditions in the lake.

Total periphyton densities were extremely variable, although differences between station were not statistically significant. Periphyton growth was influenced by complex interactions of localized environmental factors, such as currents, turbidity and nutrient concentrations, with more generalized seasonal effects. Dissolved oxygen levels below Clarks Hill Dam had little or not effect on the periphyton community, while current velocity and turbidity were likely the most important factors controlling periphyton growth below the dam and in the lake. Effects from construction of the Richard B. Russell Dam on the Savannah River were not apparent from examination of the periphyton community at Station 9.

Species diversity was variable but generally did not show overall trends among lake stations. At Station 5, however, reduction of species diversity corresponded to high total phosphate concentration in the Georgia Little River. This suggested environmental stress caused by phosphate loading. However, the periphyton communities sampled during the present study were generally diverse and were indicative of the mesoeutrophic description given the Clarks Hill Lake in 1973.

LITERATURE CITED

APHA. 1980. Standard methods for the examination of water and wastewater, 15th ed. American Public Health Association, Washington, D.C. 874 pp.

Barr, J.A., J.G. Goodnight, J.P. Sall and J.T. Helwig. 1976. The user's guide to SAS 76. Sparks Press of Raleigh, N.C. 329 pp.

Bick, H. 1972. Ciliated protozoa. World Health Organization, Geneva. 198 pp.

Duke Power Company. 1978. Baseline environmental summary report on the Broad River in the vicinity of Cherokee Nuclear Station, L.L. Olmsted and A.S. Leiper, eds. Duke Power/78-06.

Edmondson, W.T.. 1959. Freshwater biology. John Wiley and Sons, Inc. New York, N.Y. 1248 pp.

EPA (Environmental Protection Agency). 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. C.I. Weber, ed. EPA 670/4-73-001. U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio.

______________________________. 1976. National eutrophication survey. Report on Clark's Hill Reservoir. Working paper series No. 287, EPA Region IV, U.S. Environmental Protection Agency.

Hustedt, F. 1930. Die susswasser-flora mitteleuropas. Verlag von Gustav Fischer, Deutschland. 466 pp.

Lowe, R.L. 1974. Environmental requirements and pollution tolerance of freshwater diatoms. U.S. Environmental Protection Agency, Cincinnati, Ohio. 333 pp.

McIntyre, C.D. 1966. Some effects of current velocity on periphyton communities in laboratory streams. Hydrobiologica 27, (559-70).

Patrick, R. 1970. Diatom communities in John Cairns, Jr., ed. The structure and function of freshwater microbial communities. Research Division Monograph 3. Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061. pp 151-164.

Patrick R., and C.W. Reimer. 1966. The diatoms of the United States, exclusive of Alaska and Hawaii, Vol. 1. Monographs of the Academy of Natural Sciences of Philadelphia. 688 pp.

LITERATURE CITED (continued)

Patrick R., and C.W. Reimer. 1975. The diatoms of the United States, exclusive of Alaska and Hawaii, Vol. 2, Part 1. Monographs of the Academy of Natural Sciences of Philadelphia. 213 pp.

Phinney, H.K., and C.D. McIntyre. Effect of temperature on metabolism of periphyton communities developed in laboratory streams. Limnol. Oceangr. 10, 341-4.

Prescott, G.W. 1962. Algae of the western Great Lakes area. Wm. C. Brown Company Publishers, Dubuque, Iowa. 977 pp.

Prescott, G.W., H.T. Croasdale, and W.C. Vinyard. 1975. A synopsis of North American desmids, Part II, Desmidiaceae: Placodermae Section I. University of Nebraska Press, Lincoln, Nebraska. 275 pp.

Skuja, H. 1948. Taxonomie des phytoplanktons einiger seen in upland, Schweden. Symb. Botan. Upsal. 9:1-399.

Smith, G.M. 1950. The fresh-water algae of the United States. McGraw-Hill Book Company, New York. 719 pp.

Sreenivasa, M.R., and H.C. Duthie. 1973. Diatom flora of the Grand River, Ontario, Canada. Hydrobiol. 42:161-224.

Starrett, W.E., and R. Patrick. 1952. Net plankton and bottom microflora of the Des Moines River, Iowa. Proc. Academy of Natural Science, Philadelphia, Pa. 104:219-243.

Utermohl, H. 1958. Zur vervollkommnung der quantitativen phytoplankton-methodek. Mitl. Intern. Ver. Limnol. 9:1-38.

USACOE (U.S. Army Corps of Engineers). 1980. Water quality management studies, technical report ACF 80-1 (interim report). Lake Seminole. April-November 1978.

Van Heurck, H. 1896. A treatise on the Diatomaceae. Translated by W. E. Baxter. W.E. Baxter, Ltd. London. 559 pp.

Walton, L.B. 1915. A review of the described species of the order Euglenoidina Bloch class Flagellata (protozoa) with particular reference to those found in the city water supplies and other localities of Ohio. Ohio Biological Survey Bulletin 4. The Ohio State University Bulletin Vol. XIX, No. 5. 116 pp.

Weber, C.I. 1966. A guide to the common diatoms at water pollution surveillance system stations. PB-230-249, U.S. Environmental Protection Agency. 101 pp.

Whitford, L.A., and G.L. Schumacher. 1961. Effect of current on mineral uptake and respiration by a freshwater alga. Limnol. Oceangr. 6, 423-5.

LITERATURE CITED (continued)

Whitford, L.A., and G.L. Schumacher. 1964. Effect of current or respiration and mineral uptake on *Spirogyra* and *Oedogonium*. Ecology, 45, 168-70.

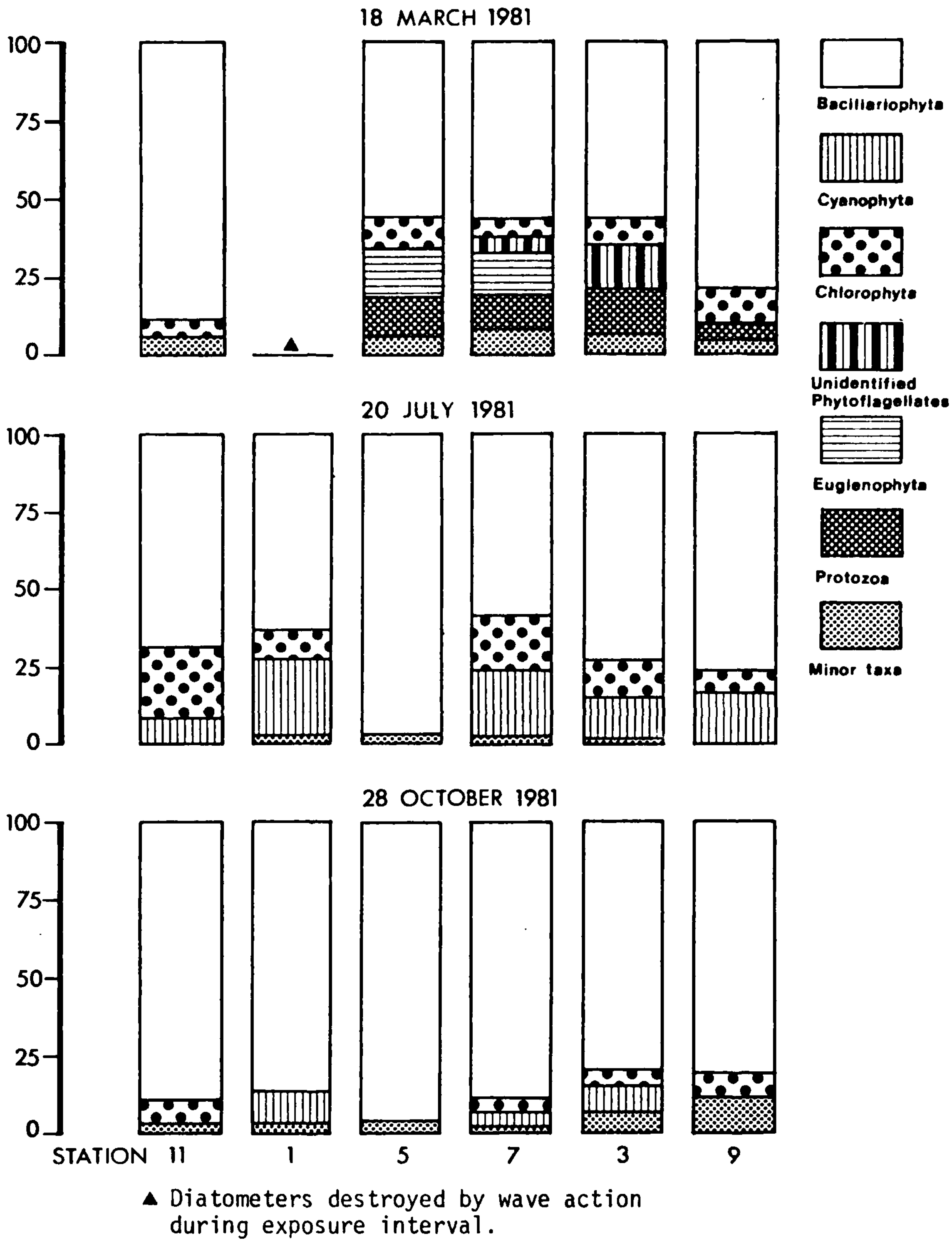


Figure G-1. Percentage composition of major periphyton groups, Clarks Hill Lake, 1981.

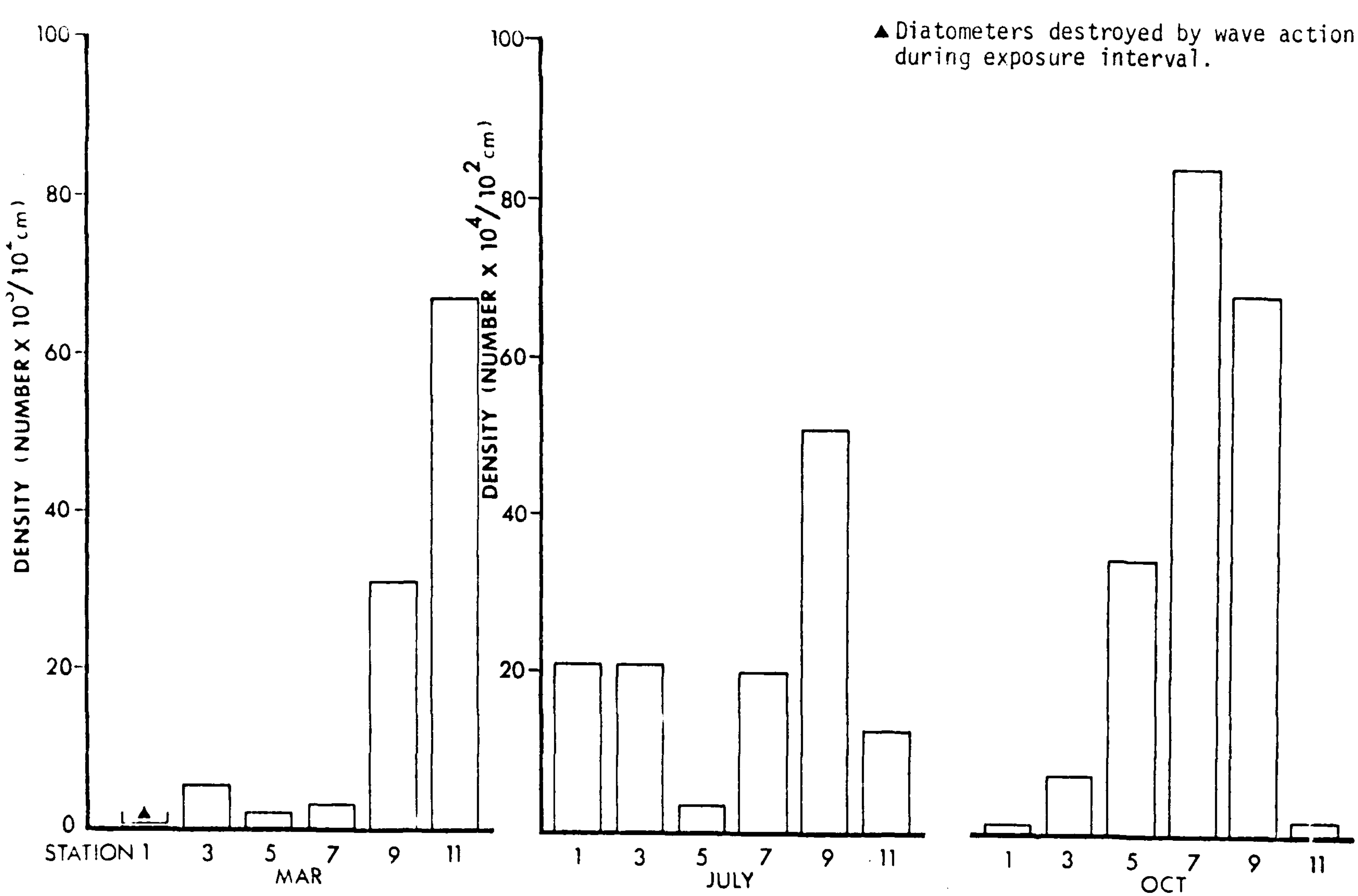


Figure G-2. Total periphyton densities by stations, Clarks Hill Lake, 1981.

TABLE G-1

PERIPHYTON SPECIES
CLARKS HILL LAKE
18 MARCH - 28 OCTOBER 1981

BACILLARIOPHYTA

Achnanthes exigua
A. lanceolata
A. lanceolata v. dubia
A. linearis
A. linearis f. curta
A. microcephala
A. minutissima
Amphora ovalis
A. ovalis v. affinis
A. veneta
Asterionella formosa
A. formosa v. gracillima
Cocconeis placentula
Cyclotella stelligera
Cymbella affinis
C. angustata
C. lunata
C. minuta
C. minuta v. silesiaca
C. tumida
Cymbella sp.
Epithemia sp.
Eunotia curvata
E. pectinalis
E. pectinalis v. minor
Fragilaria construens
F. inflata
F. intermedia
F. pinnata
F. vaucheriae
Fragilaria sp.
Frustulia rhomboides v. saxonica
Frustulia sp.
Gomphonema acuminatum
G. angustatum
G. augur
G. gracile
G. olivaceum
G. parvulum
G. truncatum
Gomphonema sp.
Hannaea arcus
Melosira ambigua

BACILLARIOPHYTA (continued)

M. distans
M. granulata
M. varians
Meridion circulare
Navicula bicapitellata
N. cryptocephala
N. cryptocephala v. veneta
N. elginensis
N. hungarica
N. mutica
N. notha
N. pupula
N. rhynchocephala
N. viridula
N. viridula v. linearis
N. viridula v. rostellata
Navicula sp.
Nitzschia acicularis
N. acicularis v. closterioides
N. capitellata
N. dissipata
N. filiformis
N. hungarica
N. Kutzingiana
N. palea
N. parvula
N. sublinearis
Nitzschia sp.
Pinnularia subcapitata
Pinnularia sp.
Surirella linearis
Synedra actinastroides
S. delicatissima
S. fasciculata
S. filiformis v. exilis
S. pulchella
S. radians
S. rumpens
S. ulna
Synedra sp.
Tabellaria fenestrata
T. flocculosa

CH5
TABLEG-1

TABLE G-1
(continued)
PERIPHYTON SPECIES
CLARKS HILL LAKE
18 MARCH - 28 OCTOBER 1981

CHRYSOPHYTA
- Dinobryon divergens
- D. sociale
- Mallomonas sp.
- Synura sp.

CRYPTOPHYTA
- cryptophyte sp.

CHLOROPHYTA
- Ankistrodesmus convolutus
- A. falcatus
- A. falcatus v. mirabilis
- Botryococcus sp.
- Bulbochaete sp.
- Characium ambiguum
- Characium sp.
- Chlamydomonas sp.
- Cladophora sp.
- Closterium sp.
- Cosmarium abbreviatum
- C. angulosum v. concinnum
- C. quadrum v. minus
- Cosmarium sp.
- Dictyosphaerium Ehrenbergianum
- D. pulchellum
- Franceia sp.
- Golenkinia radiata
- Gonatozygon aculeatum
- Gonatozygon sp.
- Kirchneriella lunaris v. irregularis
- K. obesa
- K. obesa v. major
- Lagerheimia quadriseta
- Mougeotia sp.
- Oedogonium sp.
- Oocystis pusilla
- O. pyriformis
- Palmodictyon varium
- Planktosphaeria gelatinosa
- Scenedesmus abundans
- S. acuminatus
- S. bijuga
- S. obliquus
- S. quadricauda

CHLOROPHYTA (continued)
- Scenedesmus sp.
- Spirogyra sp.
- Staurastrum chaetoceros
- S. clevei
- S. gladiosum
- S. striolatum
- S. tetracerum
- Staurastrum sp.
- Stigeoclonium subsecundum
- Stigeoclonium sp.
- Tetraedron caudatum
- T. minimum
- T. trigonum
- Tetraedron sp.
- Ulothrix sp.

CYANOPHYTA
- Anabaena sp.
- Aphanocapsa sp.
- Aphanothece sp.
- Calothrix sp.
- Chroococcus dispersus
- C. dispersus v. minor
- Gloeocapsa sp.
- Gomphosphaeria lacustris
- Lyngbya spp.
- Marssoniella elegans
- Merismopedia tenuissima
- Microcystis incerta
- Microcystis sp.
- Oscillatoria tenuis
- Oscillatoria spp.
- Rhabdoderma lineare

EUGLENOPHYTA
- Euglena sp.
- Trachelomonas volvocina
- Trachelomonas sp.
- euglenoid sp.

PYRRHOPHYTA
- Peridinium inconspicuum
- dinoflagellate sp.

TABLE G-1
(continued)
PERIPHYTON SPECIES
CLARKS HILL LAKE
18 MARCH - 28 OCTOBER 1981

PROTOZOA
- *Difflugia* sp.
- *Diplosigopsis siderothece*
- *Domatomonas* sp.
- *Peritricha* sp.
- *Salpingorhiza pascheriana*
- *Vorticella* sp.

OTHERS
- nematodes
- phytoflagellates

CH5
TABLEG-1

TABLE G-2

SUMMARY OF PERIPHYTON DENSITY AND PERCENTAGE COMPOSITION[a]
CLARKS HILL LAKE
18 MARCH 1981

	Station					
Taxon	1	3	5	7	9	11
Bacilliariophyta	-[b]	2,729 (56)	1,074 (57)	1,696 (58)	21,422 (79)	58,904 (88)
Chrysophyta	-	30 (<1)	15 (1)	0	60 (<1)	0
Chlorophyta	-	453 (9)	190 (10)	197 (7)	3,388 (12)	3,682 (5)
Cryptophyta	-	14 (<1)	12 (1)	0	0	0
Cyanophyta	-	59 (1)	0	49 (2)	432 (2)	721 (1)
Pyrrhophyta	-	24 (<1)	31 (2)	0	0	216 (<1)
Euglenophyta	-	696 (14)	26 (1)	211 (7)	65 (<1)	796 (1)
Protozoa	-	103 (2)	302 (16)	378 (13)	272 (1)	344 (1)
Others	-	739 (15)	237 (13)	380 (13)	1,621 (6)	2,289 (3)
Total Periphyton		4,847	1,887	2,911	27,260	66,952

[a]Density values are given in number of individuals per square centimeter; parentheses contain percentage composition values.

[b]Diatometers were destroyed by wave action during exposure interval.

CHVI
TABLEG-2

TABLE G-3

SUMMARY OF PERIPHYTON DENSITY AND PERCENTAGE COMPOSITION[a]
CLARKS HILL LAKE
20 JULY 1981

	Station					
Taxon	1	3	5	7	9	11
Bacilliariophyta	132,949 (64)	156,570 (73)	37,112 (97)	117,646 (59)	388,271 (76)	91,304 (69)
Chrysophyta	0	0	0	450 (<1)	0	0
Chlorophyta	19,127 (9)	25,321 (12)	839 (2)	32,856 (17)	34,213 (7)	30,183 (23)
Cryptophyta	1,801 (1)	0	0	1,751 (1)	0	0
Cyanophyta	51,930 (25)	29,483 (14)	403 (1)	44,631 (23)	91,616 (18)	9,744 (7)
Pyrrhophyta	600 (<1)	450 (<1)	0	0	0	0
Euglenophyta	600 (<1)	327 (<1)	0	450 (<1)	0	0
Protozoa	0	0	0	0	0	0
Others	1,700 (1)	2,521 (1)	0	450 (<1)	0	788 (1)
Total Periphyton	208,707	214,672	38,354	198,234	514,100	132,019

[a]Density values are given in number of individuals per square centimeter; parentheses contain percentage composition values.

CHVI
TABLEG-3

TABLE G-4

SUMMARY OF PERIPHYTON DENSITY AND PERCENTAGE COMPOSITION[a]
CLARKS HILL LAKE
28 OCTOBER 1981

Taxon	Station 1	3	5	7	9	11
Bacilliariophyta	6,817 (86)	60,152 (80)	329,455 (94)	755,045 (89)	560,596 (81)	15,761 (89)
Chlorophyta	56 (<1)	4,142 (5)	6,942 (1)	36,144 (4)	76,974 (11)	1,354 (7)
Cryptophyta	45 (<1)	263 (<1)	0	0	1,373 (<1)	0
Cyanophyta	879 (11)	6,256 (8)	10,064 (2)	48,066 (5)	15,570 (2)	430 (2)
Pyrrhophyta	45 (<1)	771 (1)	0	0	0	0
Euglenophyta	0	683 (<1)	1,352 (<1)	1,892 (<1)	0	0
Protozoa	0	350 (<1)	0	0	0	0
Others	45 (<1)	2,190 (2)	0	1,892 (<1)	29,918 (4)	0
Total periphyton	7,887	74,807	347,813	843,039	684,431	17,545

[a]Density values are given in number of individuals per square centimeter; parentheses contain percentage composition values.

CHVI
TABLEG-4

TABLE G-5

RELATIVE ABUNDANCE (%) OF MAJOR PERIPHYTON SPECIES[a]
CLARKS HILL LAKE
18 MARCH - 28 OCTOBER 1981

Taxon	18 March						20 July						28 October					
	1[b]	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7	9	11
BACILLARIOPHYTA																		
Achnanthes microcephala				6	13	47	25	12					24	9	12	27	27	40
A. minutissima					6	5		18	76	29	54	36						
Cymbella minuta			7	7														
Eunotia curvata												9						
Fragilaria construens				8				13										
Fragilaria sp.							19											
Gomphonema gracile												5		5	12	7	18	
G. parvulum		6	22	24									13		9			20
Melosira varians		9			8													
Navicula notha													5	18			10	
Synedra filiformis v. exilis					6													
S. rumpens						6	5			9			34		51	37	14	11
Synedra sp.														10				
pennate diatom spp. <20μ		6	6	9				7		9				5				
centric diatom spp. <20μ				5														
CHLOROPHYTA																		
coccoid green algae					9					7		14						
CYANOPHYTA																		
Chroococcus dispersus							15			8								
Oscillatoria spp.							8	8		12	12		11			6		
EUGLENOPHYTA																		
Trachelomonas sp.		13		6														
PROTOZOA																		
Diplosigopsis siderothece			16	6														
OTHERS																		
phytoflagellates <10μ		15	11	13	6	—	—	—	—	—	—	—	—	—	—	—	—	—
Total Relative Abundance (%) of Major Periphyton Species		49	62	84	48	58	72	58	76	74	66	64	87	47	84	77	69	71

[a]Tabulated percentage values include all species that comprised 5 percent or more of the total periphyton community in at least one sample.

[b]Diatometers were destroyed by wave action during exposure interval.

TABLE G-6

STATISTICAL COMPARISON OF TOTAL PERIPHYTON DENSITIES
CLARKS HILL LAKE
18 MARCH - 28 OCTOBER 1981

ANALYSIS OF VARIANCE: STATIONS

Source	DF	Sum of squares	Mean square
Model	5	19.11182607	3.82236521
Error	45	178.11901090	3.95820024
Corrected total	50	197.23083697	

Source	DF	Type I SS	F Value	PR > F
Station	5	19.11182607	0.97	0.4489

CHVI
TABLEG-6

TABLE G-7

PERIPHYTON SPECIES DIVERSITY
CLARKS HILL LAKE
18 MARCH - 28 OCTOBER 1981

	Station					
Date	1	3	5	7	9	11
18 March						
number of species	-[a]	46	42	46	49	43
diversity index ($\bar{d}$)	-	4.468	3.996	4.613	3.979	3.397
equitability (e)	-	0.711	0.555	0.788	0.470	0.351
20 July						
number of species	42	42	29	53	32	41
diversity index ($\bar{d}$)	3.608	4.098	1.806	3.978	2.843	3.622
equitability (e)	0.419	0.597	0.156	0.434	0.313	0.433
28 October						
number of species	18	46	25	30	35	30
diversity index ($\bar{d}$)	2.769	4.586	2.567	2.967	3.467	3.070
equitability (e)	0.527	0.773	0.325	0.366	0.453	0.395

[a]Diatometers were destroyed by wave action during exposure interval.

CH5
TABLEG-7

EXECUTIVE SUMMARY

The 1981 physicochemical and biological monitoring of Clarks Hill Lake, Georgia and South Carolina, was conducted in response to Contract No. DACW 21-81-C-0011 for the Department of the Army, Savannah District Corps of Engineers. The objectives of the study were to 1) characterize any environmental or water quality problems in the lake, 2) obtain data to develop guidance for lake control/discharge water quality relationships and 3) establish baseline conditions for future comparisons and to facilitate coordination of state agencies in implementing watershed pollution control measures.

Sampling was conducted at 20 locations in Clarks Hill Lake, its tributaries and portions of the Savannah River downstream from the dam. Water and sediment physical and chemical parameters; macroinvertebrate, phytoplankton, zooplankton and periphyton community composition and density; bacteriological parameters; and pesticide and heavy metal concentrations from tissues of mollusc (*Corbicula*), white catfish and largemouth bass were analyzed.

Physicochemical Parameters

Clarks Hill Lake is characterized by large annual temperature variations and development of strong thermal gradients during summer stratification. Surface water temperature ranged from 9°C in February to 32°C in June. The lowest recorded temperature was 6.5°C at a depth of 43 m near the dam in February. Thermal stratification of the lake was observed in June with the thermocline located at a depth of 6 to 8 m. By late August, the thermocline had descended to a depth of 10 to 12 m at most lake stations. During this period, depletion of dissolved oxygen in the deep hypolimnion occurred. Dissolved oxygen was lowest at stations in the Georgia and South Carolina Little Rivers where measurements below the thermocline were less than 1.0 mg/liter. Clarks Hill Lake waters are soft and have a low carbonate-bicarbonate buffering capacity, resulting in fluctuations in pH, conductivity and oxidation-reduction potentials between the epilimnion and hypolimnion during thermal stratification. Reduction and subsequent leaching of iron and manganese from bottom sediments into the water column occurred when anaerobic conditions prevailed. Decreases in pH and oxidation-reduction potentials were concomitant with decreases in dissolved oxygen concentrations.

The hydroelectric facility at Clarks Hill Dam draws deep hypolimnetic waters from the lake for electrical production. During thermal stratification of the lake, the hypolimnion becomes depleted of dissolved oxygen. Dissolved oxygen measurements of waters discharged into the Savannah River below the dam during summer stratification periods were below the Environmental Protection Agency minimum criteria of 5.0 mg/liter. However, 1981 was a year of reduced water discharge rate because of the severe lack of rainfall. Under normal operating conditions, discharge turbulence would result in greater dissolved oxygen concentrations below the dam. By late October, with winter mixing of the lake in progress, dissolved oxygen and other physicochemical parameters showed a nearly homogeneous distribution throughout the water column. Winter mixing or turnover of Clarks Hill Lake most likely continues until sometime in March or April.

Clarks Hill Lake primary productivity is limited throughout most of the year by orthophosphate and nitrate-nitrite levels. However, total phosphate levels in Clarks Hill Lake exceed concentrations recommended by the Environmental Protection Agency to prevent the development of biological nuisances and to control eutrophication. The tributaries are the major sources of phosphorus for Clarks Hill Lake. Although total phosphate concentrations are high, they are within the range of those observed in other southeastern reservoirs and lakes.

Determination of various pesticide concentrations in sediments and in tissue samples from the mollusc *Corbicula*, white catfish and largemouth bass showed no apparent contamination or biomagnification of pesticides within Clarks Hill Lake. Heavy metal concentrations in sediments, tissues and whole-water samples were generally higher at tributary stations as compared to lake stations, although trends were not consistent.

Grain size determinations showed that Clarks Hill Lake bottom sediments had a medium sand substrate, except at Station 6 where the substrate was of very fine sand. Mean grain sizes at the lake stations in September were much finer than those observed in March. This was an artifact resulting from the change in station locations between sampling periods. The significant drop in lake water levels between sampling periods necessitated moving stations farther offshore during September. Only slight changes were observed in mean grain sizes of bottom substrates at Savannah River Stations 11 and 12 between sampling periods.

Biological Parameters

Fecal coliform levels at state parks and other locations at Clarks Hill Lake were within maximum permissible values for all recreational and agricultural uses and for public drinking water supplies given complete treatment.

The most important phytoplankton groups in Clarks Hill Lake were green algae, diatoms and blue-green algae. Total phytoplankton density ranged from 0.9×10^6 to 11.4×10^6 cells per liter. These density levels were similar to those reported for other lakes in the southeast, including Lake Seminole, Florida, Lake Fontana, North Carolina, and Lake Sidney Lanier, Georgia. These values were of similar magnitude to density levels in Clarks Hill Lake in 1973. The range in corrected chlorophyll-a concentration was 1.27 to 12.69 mg/m^3. Chlorophyll-a concentration during the present study exceeded that measured in the Georgia Little River during 1973. A seasonal pattern of increasing productivity from early spring through fall was observed.

Phytoplankton standing crop was high in the Georgia and South Carolina Little Rivers and in the Broad River and lowest near the dam. The progressive decrease in phytoplankton standing crop from the tributaries to the dam corresponded to the distribution of total phosphate within the lake and reflected the continued influence of phosphate input to the lake. Corrected chlorophyll-a concentration and distribution and the occurrence of major phytoplankton taxa (Cyclotella and Melosira species, Nitzschia acicularis, Tabellaria fenestrata and Ankistrodesmus falcatus) were similar to those observed in several eutrophic lakes in the southeast and indicated nutrient enrichment within the lake since 1973. However, present nutrient concentrations are below critical values at which algal blooms commonly occur, so undesirable water quality conditions resulting from widespread blooms are unlikely.

The zooplankton community at Clarks Hill Lake was similar in composition and abundance to that in other southeastern lakes and reservoirs. Rotifers were the predominant organisms in terms of density and number of taxa observed. Keratella cochlearis and Polyarthra vulgaris were predominant at all lake and tributary stations. These two species were also predominant at Lake Sidney Lanier during a similar water quality investigation. Copepods and cladocerans were secondary to rotifers in density and in the number of taxa observed. Total zooplankton densities were lowest in June, highest in October and ranged between 5.67 and 310.83 individuals per liter. Comparisons of zooplankton densities showed significant differences among stations. As with phytoplankton densities, higher productivity was found at those stations located in tributaries entering Clarks Hill Lake than in the lake proper. High zooplankton densities in the tributaries are likely a response to the high food availability provided by the phytoplankton.

Periphyton composition in Clarks Hill Lake was typical of communities reported in other southeastern impoundments. Diatoms were the predominant taxa. The relative abundance of all major groups, including green algae and blue-green algae, varied seasonally.

Periphyton density and species diversity was variable among lake stations. Differences in periphyton densities among stations were not statistically significant. Periphyton growth was influenced by complex interactions of localized environmental factors such as water currents, turbidity and nutrient concentrations. Below Clarks Hill Dam, dissolved oxygen levels had little or no effect on the periphyton community, while current velocity and turbidity were likely the most important factors controlling periphyton growth. Effects from construction of the Richard B. Russell Dam were not apparent from examination of t _ periphyton community below this dam at Station 9. At Station 5, reduced species diversity corresponded to high total phosphate levels in the Georgia Little River. This suggests environmental stress caused by phosphate loading. The periphyton communities sampled during the present study were generally diverse and characteristic of mesoeutrophic waters as described for Clarks Hill Lake in 1973.

Benthic macroinvertebrate density and diversity in Clarks Hill Lake was low. The benthic community was predominated by Corbicula fluminea and, secondarily, by tubificid worms and chironomid insects. Macroinvertebrate density, biomass and diversity were generally highest in the spring and lowest in midsummer. This seasonal distribution is typical of freshwater habitats. Statistical differences in macroinvertebrate density and biomass among stations were related to habitat variations. No significant differences were found when benthic communities were compared by depth. However, this may have been a function of receding water levels during 1981. In comparison to other lake stations, Station 9, located below the Richard B. Russell Dam, had low macroinvertebrate density and diversity but high biomass. High biomass at Station 9 resulted from the large population of Corbicula found there.

The drift macroinvertebrate fauna also had low density and diversity. The community was predominated by chironomid insects. While the chironomid species found at Clarks Hill Lake are often associated with organically polluted waters, they are not restricted to such habitats. The drift fauna was at its peak in midsummer and at its low point in the fall. Unlike the benthic community, the drift macroinvertebrates at Station 9 had the highest density and second highest biomass and diversity of all the lake stations.

Statistical analyses showed that the drift macroinvertebrate fauna was similar among lake stations, with the exception of Station 1. The fauna at Station 1 was adversely affected by wind-generated turbulence that prevented the colonization of the artificial substrate samplers placed there. The drift fauna at Station 11 in the Savannah River was affected by turbulence associated with water release from the Clarks Hill Dam. Effects were primarily limited to the west side of the river below the dam. No statistical differences were found when drift community parameters were compared by depth.

When compared with the benthic and drift faunas of Lake Sidney Lanier, the macroinvertebrate fauna of Clarks Hill Lake was generally lower in density and higher in biomass and diversity. These differences were attributed to different physical characteristics of the two lakes.

The overall trophic condition of Clarks Hill Lake can be described as mesotrophic, characteristic of waters with moderate nutrient concentrations. However, data from major tributary waters entering the lake suggest that the Georgia and South Carolina Little Rivers, the Broad and upper Savannah Rivers are eutrophic. This assessment is in general agreement with the 1973 survey conducted at Clarks Hill Lake.

RECOMMENDATIONS

The 1981 physicochemical and biological monitoring survey characterized environmental conditions in Clarks Hill Lake and provided the baseline data for future surveys. This study showed that the Georgia and South Carolina Little Rivers and the Savannah and Broad Rivers, tributaries to Clarks Hill Lake, influence water quality in the lake. Similarly, lake waters from the hypolimnion at the face of the dam influence water quality in the Savannah River downstream from the dam. Additional studies should thus provide the data necessary to monitor the influence of the tributaries upon Clarks Hill Lake and the influence of the lake upon the river below the dam. The following recommendations are suggested.

1. Sampling Frequency

   Sampling every year would provide the best documentation of trends in physicochemical and biological parameters and, in turn, a more solid base for lake management than could be obtained from less frequent sampling. Monitoring specific indicators (listed below), rather than the whole spectrum of parameters studied in 1981, would be cost-effective means of providing the data for lake management decisions.

   Selected parameters should be sampled biannually: once in the early spring to assess conditions when the lake is well mixed and again in late summer to assess conditions when the lake is thermally stratified.

2. Station Locations

   Stations should be located in the tributary rivers, at the face of Clarks Hill Dam and in the tailwaters below the dam. These locations would provide comparable data on tributary/lake and lake/discharge water quality relationships.

3. Sampling Parameters

   a. Temperature, dissolved oxygen, pH, conductivity and oxidation-reduction potential should be profiled to permit characterization of the water column and provide correlative data for the other parameters studied.

   b. The nutrients total phosphate, orthophosphate, nitrate-nitrite and ammonia should be measured because they determine lake productivity and subsequent trophic structure.

   c. Other chemical parameters that should be measured are total organic carbon, biochemical oxygen demand, chemical oxygen demand and un-ionized hydrogen sulfide. These parameters are used to characterize the trophic condition of waters and are important in understanding the overall dynamics of an aquatic environment.

d. Phytoplankton and chlorophyll-a should be analyzed to estimate relative productivity within the lake.

e. Macroinvertebrates should be analyzed to provide an indication of the overall trophic condition of the lake. Because macroinvertebrates exhibit limited motility and relatively long life spans, the composition of the macroinvertebrate community is a function of environmental conditions during the recent past and is a valuable indicator of environmental conditons.

The preceding specific indicators are considered to be the minimum requirements for on-going lake water quality survellience and, ideally, should be monitored every year. Upon completion of the Richard B. Russell Dam, re-sampling of all 1981 baseline study parameters are recommended to evaluate potential changes in Clarks Hill Lake resulting from operation of this dam.

END

FILMED

1-86

DTIC